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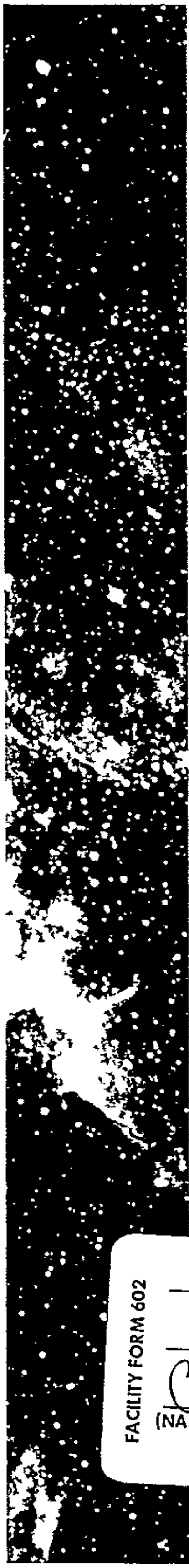

DEVELOPMENT OF CIRCUITRY FOR A MULTIKILOWATT TRANSMITTER FOR SPACE COMMUNICATIONS SATELLITES

INTERIM TECHNICAL REPORT

GENERAL ELECTRIC

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DEVELOPMENT OF CIRCUITRY
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INTERIM TECHNICAL REPORT

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Contract No. NAS 8-24771

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ABSTRACT

This report covers the first half of a contract on the "Development of Circuitry for a Multikilowatt Transmitter for Space Communications Satellites". This effort is a continuation of a previous study on definition of space transmitters with emphasis on space TV broadcast satellites; it will culminate in a breadboard of a transmitter type applicable to a UHF AM-TV broadcast satellite. Development of about half of the transmitter was performed during the reporting interval. Of the transmitter circuits, initial development is complete for a 125 watt visual channel driver at 825.25 MHz and nearly complete for a 500 watt FM aural channel amplifier at 829.75 MHz. A crowbar circuit for dc breakdown protection has been bench tested and will be included in the final transmitter assembly. Also, RF waveguide components have been completed for inclusion in the transmitter tests. An initial approach has been selected for the high efficiency Doherty UHF visual channel amplifier, and a controlled carrier circuit has been designed to achieve dc power conservation in the AM TV application. Test plans have been prepared for the transmitter tests and also for testing selected RF waveguide and coaxial components in a vacuum environment to assess electrical breakdown potential.

The program continuation will include development of the Doherty amplifier for a 5 kW peak sync level, and also of the controlled carrier circuit. Bench testing will be performed on the entire transmitter and vacuum environment testing on selected RF components.

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SECTION 1

BACKGROUND AND OBJECTIVES

1.1 PURPOSE OF THE MULTIKILOWATT TRANSMITTER PROGRAM

The major objective of the Multikilowatt Transmitter Program for space communications satellites is to place a high-power satellite transmitter in space in the early 1970's. The transmitter type to evolve will be coordinated with mission requirements established prior to the start of a prototype development; for this contract the mission is considered to be a direct or semi-direct TV broadcast function with conventional ground TV receivers, probably using improved ground antennas but operating without receiver modification. The basic results of the study, however, will be applicable over a broad spectrum of missions.

1.2 PREVIOUS STUDIES

An earlier contract (References 1 and 2) examined key systems, subsystems, and components to identify optimum high-power transmitters for space, and included investigations of specific critical problem areas. This study provided the parameters for high power space transmitter designs in the 50 watt to 20 kW range, and indicated techniques to implement thermal control measures and methods for preventing electrical breakdowns in the space environment. A recommendation leading to the present contract was to develop a high efficiency linear amplifier, specifically using the Doherty circuit,for potential use in a UHF AM TV transmitter, and to experimentally evaluate the effects of the space environment on RF components that would be used in a multikilowatt transmitter in space communications and broadcast satellites.

1.3 OBJECTIVES OF THE PRESENT CONTRACT

The two major objectives of the present contract are to breadboard a 5 kW TV transmitter incorporating a high efficiency Doherty linear amplifier, and to verify the ability of RF components to operate at high power in a vacuum environment without electrical breakdowns. These objectives involve breadboarding a linear driver and 5 kW Doherty amplifier for a UHF AM-TV signal, an aural FM amplifier at a 500 Watt output power level, the necessary waveguide components to demonstrate operation of the transmitter, controlled carrier and energy storage circuits as required for AM-TV operation, and the protective circuits to prevent catastrophic failures should some electrical fault, temporary or permanent, occur.

The result of the contract will be a breadboard that will be the basis for developing a space qualified transmitter for a UHF AM TV space broadcast or other communication system. In addition, the critical interfaces, including the environment, thermal control, and dc power, will be defined to permit the continuation of the program into space qualifiable prototype transmitter.

SECTION 2

PROGRAM APPROACH

2.1 PROGRAM PLAN

An eight task program was set up to accomplish the objectives set forth for the study of Circuitry Development for a Multikilowatt Transmitter for Space Communications Satellites. The tasks include the following, which are shown in the program plan block diagram of Figure 2-1:

TASK	TITLE
1	Transmitter System Design
2. a)	Driver (Visual Channel)
b)	Doherty High Efficiency Amplifier
3.	Aural Channel Amplifier
4.	RF Components: High Power, VSB Filter
5.	Protective Circuitry
6.	Controlled Carrier Circuit (Includes Energy Storage Filter)
7.	RF Components Environmental Testing
8.	Transmitter Tests

In addition, a final report will be prepared.

The purposes and objectives of each of the tasks are given below:

<u>Task 1. Transmitter System Design</u>

Define approach to subsystem and component implementation. Tradeoffs among the approaches to implementation of this particular transmitter are to be made with consideration for the basic circuit design, component availability and anticipated performance, and future applicability as spacecraft hardware. Items of particular

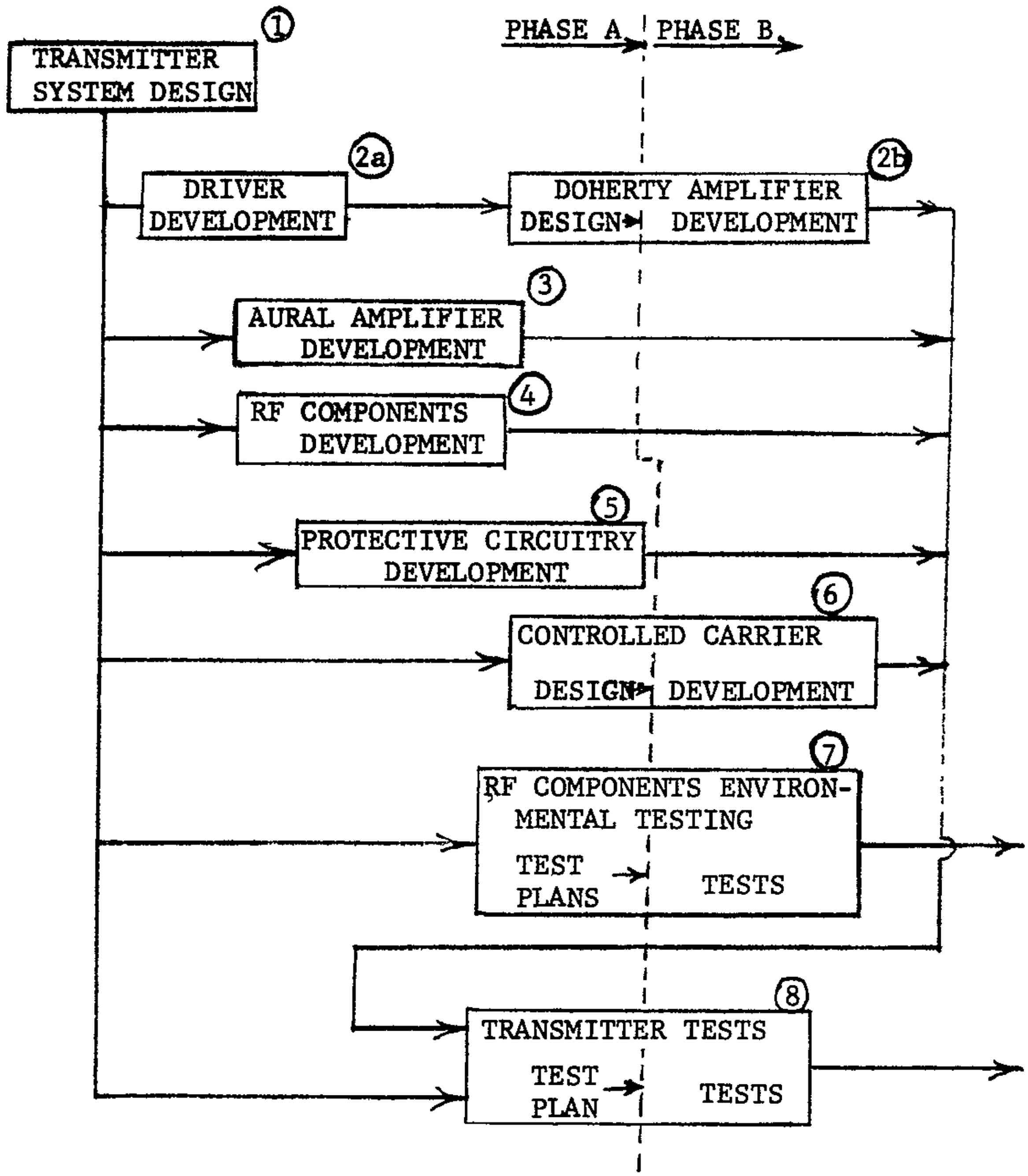


FIGURE 2-1. PROGRAM PLAN FOR MULTIKILOWATT TRANSMITTER CIRCUIT DEVELOPMENT

concern are transmission line, tube types, circuit characteristics, and initial mechanical design.

Task 2a and 2b. Visual Chain Amplifiers

Design, breadboard and component-test driver and visual rf amplifiers as required for implementation of the 5 kW (nominal peak sync level) TV transmitter. Design the high efficiency final visual rf amplifier (Doherty circuit) and develop linear driver in first half of study; develop Doherty amplifier in second half of study.

Task 3. Aural Chain Amplifiers

Design, breadboard, and component-test the power amplifier for the 500 watt (nominal CW rating) aural channel of the 5 kW TV transmitter. (The design of the final amplifier os this chain should serve as the prototype for portions of the visual chain Doherty amplifier.)

Task 4. RF Components

Design, breadboard, and component-test rf components required for implementation of the transmitter breadboard; typical components are vestigial sideband filter, color subcarrier image filter, and diplexing hybrid.

Task 5. Monitoring and Protective Circuits

Design the elements required for transmitter protection and performance monitoring and include in transmitter breadboard Typical circuit elements to be provided are crowbars, power monitors, and fault sensors.

Task 6. Controlled Carrier Design

Design a controlled carrier circuit suitable for inclusion in the breadboard TV transmitter. This will be developed in the second half of this contract. An L-C energy storage filter is to be included.

Task 7. High-Power RF Component Environment Test

Design and assemble test equipment for evaluating in a vacuum the high power rf breakdown performance of typical rf component configurations relating to those used in the breadboard TV transmitter. Ionizing and multipactor breakdown modes are to be investigated by proper instrumentation in the test circuit, and means of correcting breakdown problems will be evaluated. A test plan is to be formulated initially, but the testing will be performed in the second half of the contract.

Task 8. Transmitter Performance Tests

Provide test plan for testing the transmitter system comprised of the elements developed in tasks 1 through 6 above. Complete system tests will be performed in the second half of the contract covering performance, TV quality, and controlled carrier performance. An incidental objective of the final test program is to perform full power tests using a company developed space-type dc-to-dc power conditioner and output-stage heat pipe system. The latter tentatively has been deleted due to the re-direction of company funded program, but the power conditioner is progressing and will be tested in the late part of the testing program.

Task 9. Final Report

To be provided at end of contract.

The ultimate output of the contract will be as follows:

1. Breadboard transmitter, including all components indicated as deliverable in the overall block diagram of Figure 2-2 below;
2. Test data on the transmitter for a TV application,
3. Test data on the performance of high power rf components in a space simulated environment.

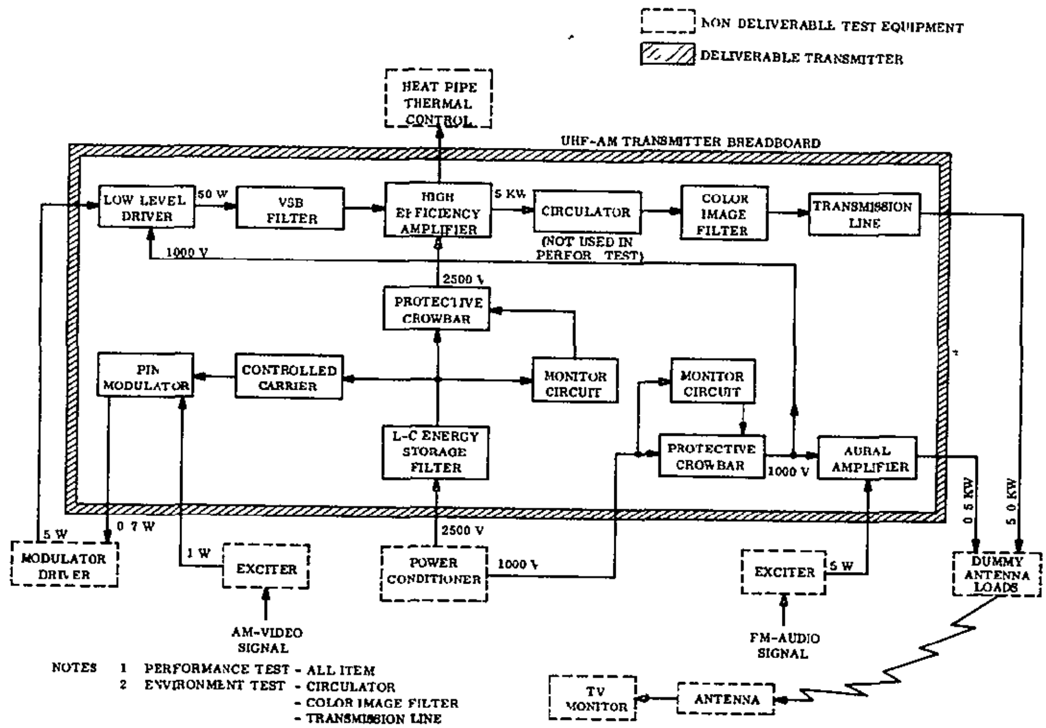


Figure 2-2. Block Diagram of Transmitter and Test Equipment

2.2 SCOPE OF EFFORT

The following provides a general indication of the scope for each of the tasks.

2.2.1 Transmitter System Design - Task 1

This task is the system definition phase of the program where the basic design of the transmitter is set, including selection of major components. The reasons behind these selections were reviewed with respect to the specifications of this system, and consideration given to new developments which might have taken place since the previous studies were completed. Then, taking into account the state of the art and transmitter system specifications, an approach to each required subsystem was defined in general terms and specifications prepared for each subsystem.

The items relating to the various subsystems as set forth in the other tasks include the following, and may consider additional items required as the study progresses:

Over-all detailed requirements, based on contract

RF Components to be used, including requirements for the vestigial sideband filter and color subcarrier image notch filter, and a comparison of waveguide and coaxial components.

Tube Selection

Doherty circuitry as derived from a 30 MHz Simulator; also other amplifier circuits

General mechanical configuration of the transmitter and supporting subsystems

Requirements for all protective circuitry, and an indication of circuitry suitable for the transmitter

Design requirements for a Controlled Carrier Circuit

These results will be used directly in defining the efforts in other tasks.

2.2.2 Visual Channel Amplifiers - Task 2

2.2.2-1 Visual Channel Driver

The task objective is to design, fabricate, and test the Driver Amplifier for the High Efficiency (Doherty) Visual Power Amplifier and associated circuitry for future use in the transmitter breadboard circuit. The driver amplifier is required in the transmitter breadboard for raising the power output level of the external exciter (5 watts) to the nominal 100 watt level required for the input to the Doherty amplifie

The driver amplifier must also have essentially linear gain characteristics over the TV signal dynamic range and adequate bandwidth to avoid excessive distortion of the television signal.

2.2.2-2 Visual Channel Doherty High Power Amplifier

This task is to provide a design for the final visual-channel amplifier based on the Doherty circuit. The design is to include input and output cavity designs, dc

circuit requirements, bias circuits, and interconnecting transmission lines at the input, output, and between the two stages. Since this is a paper design, it is subject to modifications as the development in the second half of this contract progresses. The high efficiency Doherty amplifier is required in the transmitter breadboard to provide a power output level of 5.0 kilowatts sync peak at the transmitter output terminal. The amplifier must have essentially linear gain characteristics over the TV signal dynamic range and adequate bandwidth to avoid excessive distortion of the television signal.

2.2.3 Aural Amplifiers - Task 3

This task is to design, fabricate, and test the Aural Channel Amplifier output amplifier stage and associated circuitry for later use in the transmitter breadboard circuit tests.

The aural channel amplifier is required to achieve a nominal 500 watt level. This will be driven directly by an external exciter (5 watts) and will carry a conventional FM aural signal.

2.2.4 RF Components - Task 4

This task is to provide and test the specialized rf components required for proper functioning of the breadboard transmitter to be assembled later in the contract period.

A number of rf components are required to interconnect the high-power amplifier outputs with the antenna(s) and to provide other functions such as vestigial sideband filtering, and diplexing of the aural and visual signal outputs of the transmitter. Harmonic suppression was not deemed necessary since it would not appreciably affect fundamental frequency operation of the unit, inclusion of a harmonic

filter would not measurably increase technical knowledge since filter implementation techniques are well founded. The question of potential harmonic filter breakdown will be evaluated in Task 7.

The specific waveguide components included in the system are a 3 dB hybrid, directional couplers for monitoring, a color subcarrier image notch filter, waveguide-to-coax transitions to direct the rf power into dummy loads, and a low level vestigial sideband filter to be located at the input to the transmitter's driver stage.

2.2.5 Monitoring and Protective Circuitry - Task 5

This task is to design, fabricate, and test the necessary ancillary circuitry in the high efficiency television transmitter breadboard for protection of transmitter components from damage under conditions of circuit malfunction or misadjustment, and for monitoring transmitter performance. The specific circuits will include dc crowbars to cut off the power supplies if arcing or other dc breakdowns occur, and rf power measurements to turn the signal off if a high reflected power is detected, indicating an rf fault. Control and logic circuitry will be included.

2.2.6 Controlled Carrier Circuit Design - Task 6

This task involves the design of a "controlled carrier" modulator, or attenuator, for use with the high efficiency Doherty amplifier in the 5 kW AM-TV transmitter breadboard to be assembled and tested. This circuit is to permit the power supply and conditioner to be sized to the "average" transmitter power required for the TV signal. The technique can reduce power supply and conditioner capacity requirements by as much as 40%, which is a highly significant saving in satellite and system weight and cost. The derived design will be fabricated and tested later in the contract.

2.2.7 High Power RF Component Environment Tests - Task 7

A test plan is required, describing objectives, components, techniques and test methods, and basic limits to be utilized in testing rf components for high power multipacting and ionizing breakdown under high vacuum conditions as would be encountered in a space system.

In this study, emphasis will be placed on multipactor breakdown, with an incidental consideration for avoidance of ionizing breakdown in the test system. All results on breakdown of both types will be reported.

The items to be tested are expected to be:

- Coaxial line - 3-1/8"
- Waveguide - half-height WR975
- Stepped coaxial line to identify multipacting conditions
- Stepped waveguide section to identify multipacting conditions
- 3-dB hybrid (sidewall) coupler
- Color subcarrier image notch filter

2.2.8 Transmitter Test Plan - Task 8

This task is to outline the procedures for testing the Multikilowatt TV Transmitter, following the EIA suggested methods, whenever applicable, as included in EIA Standard RS-240.[3] Transmitter tests are to demonstrate the ability of the multikilowatt transmitter to transmit a high quality TV picture with a high efficiency. Simultaneous operation of aural and visual channels is assumed in the final procedures.

The tests will be divided into three basic areas:

- Tests of performance, including efficiency, power, and gains
- Tests for TV quality factors, per EIA RS-240
- Tests for TV performance with controlled carrier circuit included.

2.3 CONSTRAINTS

Constraints on the various tasks are determined from contract requirements, results of the System Design Study of Task 1, performance requirements such as EIA Standard RS-240, and available state-of-the-art components. These are summarized briefly below.

2.3.1 System Design Study - Task 1

The contract specifies the development and initial breadboarding of a number of stages and subsystems required for a high-power, high efficiency UHF television transmitter breadboard which will lead toward the preliminary design of a multikilowatt transmitter for space applications. Program task scheduling was arranged so that all hardware design and development task technical requirements would be defined in this task. The tasks covered are:

Visual Chain Amplifiers - Task 2
- 5 kW Doherty Output Stage Design
- 50 W Class B Driver for the Doherty Amplifier

Aural Stage Amplifier - Task 3
- 500 W Class C FM Amplifier

RF Components - Task 4
- Color Image Filter
- RF Transmission Elements
- Vestigial Sideband (VSB) Filter

Monitoring and Protective Circuit - Task 5

Controlled Carrier Design - Task 6

In addition, certain assumptions and definitions were made to allow design of the subsystems to be firmly defined:

1. EIA Standard RS-240 shall be used as a guide to transmitter performance requirements and test methods.

2. UHF Television channel 73 shall be used (825.25 MHz)

3. The design of the transmitter shall not preclude later integration with the heat pipe and power conditioner systems being developed elsewhere with GE independent research (IR&D) funding.

4. Techniques applicable to, and required for, space operation shall be used wherever feasible within the limits of present technology and contract funding and schedule. Otherwise, space design requirements and approaches which might be used in future designs should be indicated and discussed wherever practicable.

The basic approaches and specifications for the transmitter subsystems are determined in this task. The approach used was:

1. Use previous MKTS and other related study results as a guide in establishing transmitter design approaches and as sources for design data. Determine preferred tubes, transmission line types, RF amplifier specifications, other circuit requirements, and supporting equipment requirements.

2. Determine if there have been recent developments, since performance of the above studies, which might have an impact on this design.

3. Determine the availability of major components required for use in the transmitter breadboard.

4. Perform design and tradeoff studies as required to arrive at an optimum design. Consider:
   a) Incorporation of space-required features where feasible.
   b) High-efficiency.
   c) High quality signal channel performance.

5. Specify or otherwise define subsystem requirements which will result in the attainment of performance objectives and a well-integrated breadboard test unit.

2.3.2 <u>Visual Channel Amplifiers - Task 2</u>

2.3.2-1 Driver Amplifier

Development of a linear rf amplifier suitable for incorporation into the TV transmitter breadboard visual amplifier chain is required as a task output. Due to gain, linearity requirements, the need to limit grid dissipation, and variations in load VSWR with drive level, it may also be necessary to include dynamic grid bias control circuitry and/or a ferrite load isolator as accessories to this rf amplifier. The need for these latter items will be defined in the design phase of the task. Design objectives for the amplifier are:

Electrical

Operating Frequency	825.25 MHz (video carrier) (tunable cavity to permit tube change)
Bandwidth	824.0 to 829.5 MHz $\pm$ 0.5 dB (min. BW)
Power Output	125 watts peak sync (capability for 200 watts peak sync would be desirable)
Power Input Level	5 watts peak sync (max.)
Gain Variation with Drive Signal Level	0.5 dB (maximum)
Phase Transfer Variation with Drive Signal Level	$\pm$ 3^o (maximum)
Efficiency	>50% at rated output into a matched load

Thermal

Cooling Method	Conduction or radiation(No forced air)
Heat Sink Temperature	100^{o}C (max)
Maximum Tube Seal Temp.	250^{o}C Maximum

Mechanical

Cavity Construction

Breadboard design should be adaptable to space-type hardware with minimal changes, the approach to be defined in the task final report. Design features should include:

Ruggedness

Avoidance of excessive mechanical stresses on the tube and other amplifier components, including thermal expansion.

Cavity should be capable of being readily dismantled for tube replacement, developmental changes, etc.

Compatibility with Breadboard Circuit

Designs should be periodically reviewed to insure compatibility with all electrical and mechanical interfaces in the breadboard circuit.

Personnel Safety - Must include considerations of:

High Voltage, rf radiation, and external hot spot temperature.

2.3.2-2 Doherty High Efficiency Amplifier Design

Design of gridded-tube rf amplifier cavities and associated circuitry in the Doherty configuration, suitable for incorporation into the MKTS III TV transmitter breadboard video amplifier chain, is required as a task output. Due to gain and linearity requirements, and the need to limit grid dissipation with variations in drive level, it will probably be necessary to include dynamic grid bias control circuitry as an accessory to this rf amplifier. Design objectives for the Doherty amplifier are:

Electrical

Operating Frequency	825.25 MHz (video carrier)
Bandwidth	824.0 to 829.5 MHz $\pm$ 0.5 dB (min. BW)
Power Output	5.0 Kilowatts peak sync
Power Input Level	65 watts peak sync (nominal) at the input terminal of the rf input power divider
Gain Variation with Drive Signal Level	1.0 dB (maximum)
Phase Transfer Variation with Drive Signal Level	$\pm$ 3° (maximum)
Efficiency Objective	$\geq$ 60% at video signal level of 25% of rated output power and $\geq$ 65% at rated peak sync power into a matched load

In addition, thermal control is required, using water cooling for the high power stages in the transmitter tests, and maintaining temperatures no greater than the following:

Heat Sink Temperature	60°C (max) for cooling water 100°C (max) for cavity elements 300°C (max) for the conduction cooled anode
ΔT Between Adjacent Tube Seals	100°C (maximum)

Maximum Tube Seal Temp.	150°C maximum at the grid seal. Other seals must observe the ΔT limit above.

Mechanical design and personnel safety are to be determined for the configuration used in the final teats, as outlined for the driver stage in the previous task discussion.

2.3.3 Aural Channel Amplifier - Task 3

Development of a gridded tube rf amplifier suitable for incorporation into the transmitter breadboard is required. This includes input and output cavity designs. Due to the need to limit grid dissipation, dynamic grid-bias control circuitry and/or a load isolator may be desirable. The need for the latter items is to be defined in the design phase of the task. Design factors are:

Electrical

Operating Frequency	829.75 MHz (aural carrier)
Bandwidth	100 KHz $\pm$ 0.5 dB (min. BW)
Power Output	500 watts CW
Input Power Drive Level	5 watts CW (max.)
Efficiency Objective	$\geq$70% at rated output into a matched load (design goal)
Circuit Configuration	DC grounded plate

Thermal

Water Cooled anode, others conduction or radiation cooled (no forced air), 100°C heat sink, tube temperatures the same as in Section 2.3.2-2 (Doherty amplifier).

Mechanical

Should have no features which preclude adaptation to a space qualified transmitter. Basically the same as for the Doherty amplifier, Section 2.3.2-2.

Personnel Safety

To be observed at all times with respect to high voltage; rf radiation, and external temperatures.

2.3.4 RF Components - Task 4

2.3.4-1 High Power Waveguide Components

This task involves the design, fabrication, and basic tests on the several rf components required in the transmitter test. The high power components are to be of half-height WR975 waveguide. Constraints are:

Color Image Filter	821.67 MHz 20 dB attenuation (goal, 15 dB acceptable) .05 dB Insertion Loss (goal) 1.10 max. VSWR, visual channel mechanically and thermally compatible with rest of transmitter and system.
Hybrid, 3dB	824 to 830 MHz sidewall coupling, 3 $\pm$ .15 dB 30 dB isolation 0.1 dB max. loss 1.05 VSWR (goal) 5.5 kW rating Mechanically and thermally compatible with rest of transmitter and system.
Transition, half-height WR 975 to 1-5/8" coax	1-5/8" line at 50 ohms 824 to 830 MHz 1.03 max VSWR 0.1 dB insertion loss Mechanically and thermally compatible with rest of transmitter and system.
Directional Couplers	Essentially the same as 3 dB hybrid but with -30 dB coupling.

2.3.4-2. Vestigial Sideband Filter

This filter is to shape the TV transmitted spectrum to conform to that of EIA Standard RS-240. An input type preceding the driver will be used since the linear amplifiers should not generate significant distortion to disturb the spectral response at the output. Thus, the filter must operate at inputs up to a 10 Watt power level obtained from the external exciter. Other design factors are:

824 to 830 MHz

20 dB minimum attenuation of unwanted lower sideband components

3 dB loss (max) over pass-band

1.5 VSWR over pass-band

Response per EIA Standard RS-240 as in Figure 2-3 (lower sideband shaping)

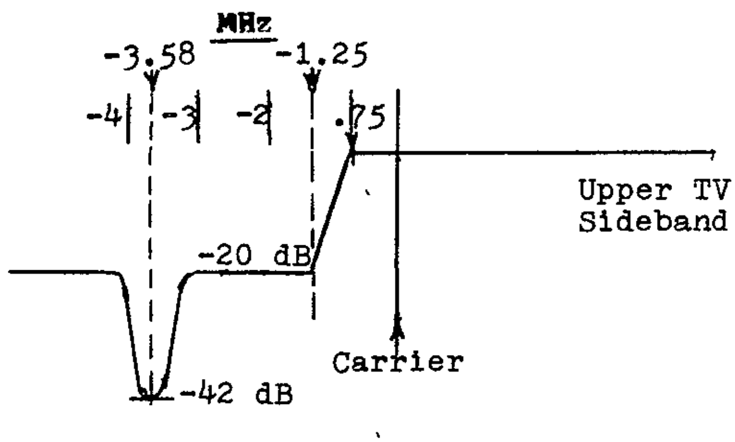


Figure 2-3. Vestigial Sideband Response

2.3.5 Monitor and Protective Circuitry - Task 5

This task generally involves design, fabrication, and testing of all monitor and protective circuits for the complete transmitter. The extent of each is as follows:

- Crowbar for Visual Channel Amplifier - A circuit which will operate upon receipt of an "excessive current fault" signal in the high efficiency amplifier anode circuit will be provided. A low impedance current path (a triggered spark gap, for example) will be provided to divert the fault current from the amplifier such that damage to amplifier components, and particularly the high power tubes, will be minimized. Typically, fault energy should be maintained below 5 joules in a tube arc situation.

- Fault Sensing and Control Logic - Provision will be made for protective circuit logic necessary for protection of visual and aural amplifiers and associated

components, including the crowbar circuit described above. This protective and control logic will be integrated as necessary with the associated laboratory test circuit items such as power supplies, cooling system, and dummy loads.

- Monitoring - monitoring points giving the necessary output signals required for transmitter monitoring by the associated test equipment will be provided. Parameters monitored will include:

  (a) Input to output signal transfer characteristics
      Gain
      Phase
      Distortion

  (b) DC to RF Power Conversion Efficiency

- Other Factors - Designs and hardware generated in this task will be adaptable as space-type circuits and hardware insofar as practical. Personnel safety provisions will be given due consideration in the design and testing efforts.

2.3.6 Controlled Carrier Circuitry - Task 6

Requirements placed on the Controlled Carrier circuitry are:

824 to 830 MHz

10 watts RF power at 60% duty factor

1.0 dB or less insertion loss

Variable loss to 6.0 dB

Time constant = 0.2 to 20 milliseconds

1.2 VSWR goal

The control is located between the external exciter and the input terminal of the driver stage, the controlling signal is derived from the average plate current requirement. Design is required in this report, and fabrication will be implemented in the second half of the contract. A selectable gray-level clamp permits level adjustment for determining the amount of carrier control to be employed.

2.3.7 High Power RF Component Environmental Tests - Task 7

This contract requires the environmental testing of several RF components which may include in descending order of significance, the several representative items listed here:

	Component	Size
1.	3-1/8 Inch Coaxial Line Section	
2.	Half Height WR 975 Waveguide Section	
3.	Coaxial Step Section, 3 1/8" Dia.	Wavelength plus 14"
4.	Waveguide Step Section, WR 975	10" x 20"
5.	3 dB Sidewall Coupler, Dual WR 975 at 1/2 height	20" x 24"
6.	Aural Notch Cavity Filter, WR 975 at 1/2 height	10" x 14"

The program plan developed in this task is based on testing these items. The immediate report is concerned only with the test plan, which is based in part on studies of rf electrical breakdown in a previous contract (reference 2). The test plan is developed around available facilities in order to achieve maximum results with a minimum expenditure.

2.3.8 Transmitter Tests - Task 8

The transmitter tests will be a complete system test including all the elements generated in the separate tasks of the contract. The test plan reported here is the basis for system tests to be performed. The tests are described in terms of test equipment required, how the equipment is assembled, the test procedure, and data expected. The planned tests are divided into the functional tests of power, efficiency, and gain measurements, followed by tests on TV performance in accordance with EIA Standard RS-240, without and with the controlled carrier circuitry affixed.

SECTION 3

RESULTS

This section summarizes the major results of each of the tasks in the first half of the contract. Detailed technical results are in Section 5.

3.1 TRANSMITTER SYSTEM DESIGN - TASK 1

3.1.1 Overall Requirements

The system design study considered the various elements of the transmitter system which would influence overall performance. Included were components, circuits, and mechanical design; these were subsequent guidelines for other task developments. The overall task used the constraints of Section 2.3.1 to formulate the task direction; these are based on various inputs from other programs as well as the EIA RS-240 TV Standard.

3.1.2 RF Components and Transmission Line

Results of previous studies[2] indicate that 3-1/8 inch 50-ohm coaxial line and half-height WR975 waveguide are reasonable choices for UHF space applications, with waveguide being the more conservative approach, both from thermal and rf breakdown considerations. Very low impedance ridged-waveguide and coaxial lines offer promise of freedom from multipactor effects; however, impedance matching requirements and higher losses are penalties for the use of these transmission line forms.

Since waveguide was more attractive, a half-height version was implemented to achieve a reduction in size and weight, but without encountering geometries leading to breakdown conditions. No additional weight reduction measures were used since they would not influence electrical performance, but would add to the program cost and delay the schedule.

For the vestigial sideband filter, a low level circuit will be used, formulated of stripline. Its power loss on a system basis will be small, if the VSBF is located prior to the linear driver stage. This filter, as well as the high power waveguide components are discussed in detail in Section 3.4 and 5.4.

3.1.3 Tube Selection

A significant part of this task was a review of available suitable tubes, and selecting the most promising for the amplifier stages to be developed. The most advanced tube available for UHF at a high power level was the L-64S derived developmental type Y1498 planar triode, selected for both the 5 kw Doherty Visual Amplifier and the 500 watt Class C Aural amplifier. Machlett's ML-8534 planar triode was selected for the visual driver; it is capable of a 125 watt output which provides a substantial power margin for driving the Doherty amplifier.

3.1.4 Transmitter Circuit

A block diagram of the transmitter is shown in Figure 3-1. In the visual channel, VSB filtering is used at the low level input rather than at the high level output to avoid substantial inefficiency; weight and volume are greatly reduced also. This approach requires a color subcarrier image filter at the output to suppress the intermodulation product at 3.58 MHz below the video carrier, which results from mixing of the video carrier and color subcarrier by the small non-linearities in the final amplifier stage.

The visual amplifier chain consists of the ML-8534 grounded-grid driver stage rated at 125 watts nominal peak sync output, and the Y1498 Doherty Amplifier which is rated at 5 kw nominal sync peak output. The driver stage is connected to the Doherty amplifier by a power splitter phase shift network which provides the appropriate drive signal levels to the two grounded-grid Doherty amplifier stages. Two approaches are proposed for the input network, and both can be tested in the second half of the program as required. WR975 half-height waveguide was selected as the transmission line, waveguide to coaxial transitions are included so that readily available coaxial dummy antenna

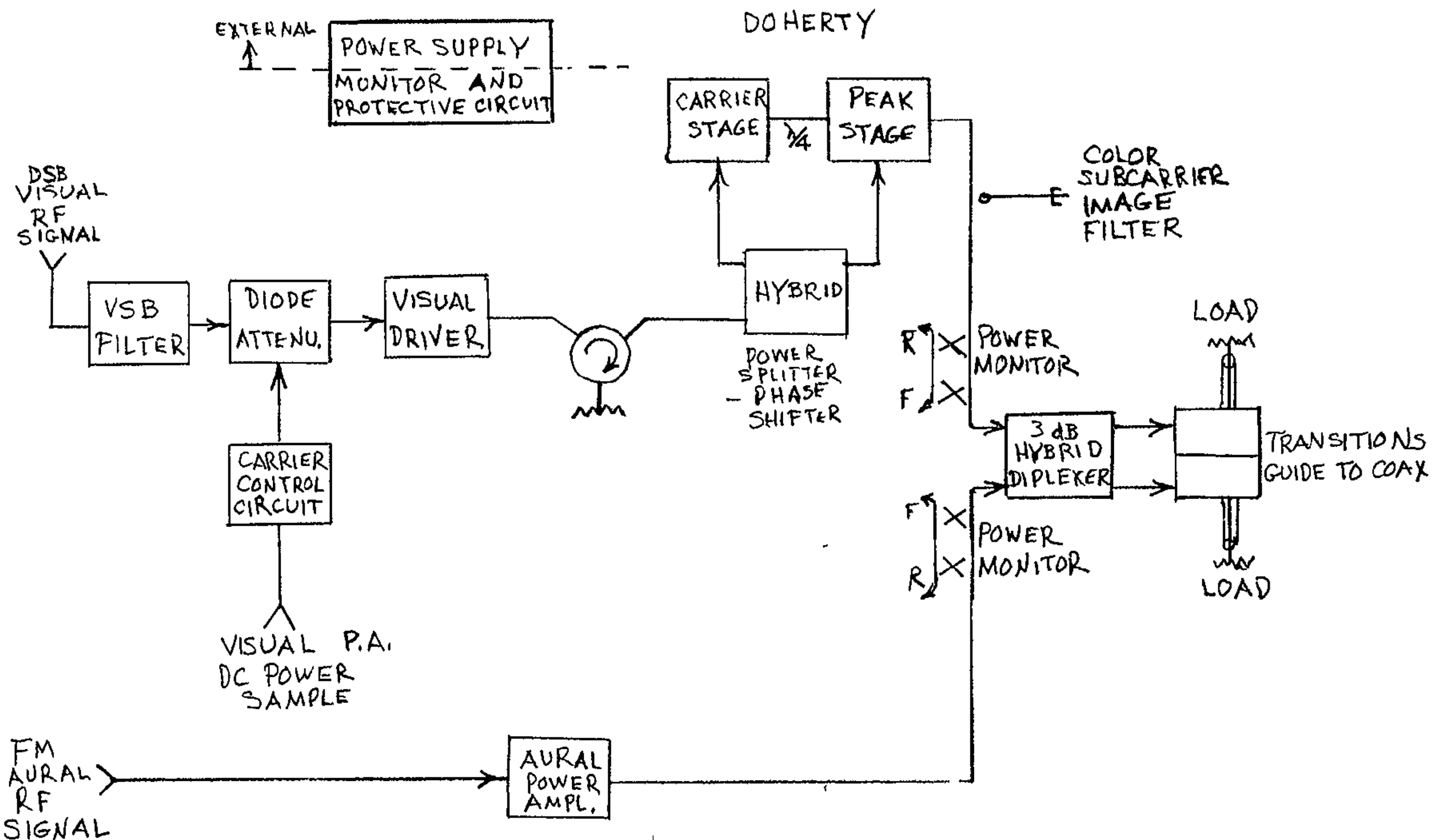


FIGURE 3-1. BREADBOARD TRANSMITTER BLOCK DIAGRAM

loads can be used to absorb the amplifier RF outputs.

The input impedances of grounded grid stages in the transmitter vary over a wide range as the drive signal level changes within the TV signal dynamic range. The 30 MHz "Doherty Simulator"(2) showed that dynamic variation of grid bias in a pre-determined manner could counteract the effects of loading variations on drive voltage. This approach permits reasonable linearity to be obtained in the Doherty circuit and has the advantage of improving efficiency, since the Class B Carrier stage of the Doherty is driven into a Class C operating region for rf output levels above "carrier level" (one-half of the sync peak voltage level). The dynamic bias circuit also provides a grid current limiting feature.

The output VSWR of the transmitter is quite high and re-flections of power reflected by the waveguide components and antenna may be nearly equal in magnitude to the reflections themselves. Tentatively, it is believed that re-reflected power will not cause excessive gain/phase ripple in the signal with normal performance levels for the gridded tube Doherty amplifier. The waveguide components have low VSWR's and thus minimize reflected (and re-reflected) power.

Based on considerations discussed above, specifications were obtained for the Video Driver and High Efficiency (Doherty) Output Amplifier stages, which are discussed in Sections 3.2 and 3.3, which follow. Wherever practical, techniques which are suitable or adaptable for space will be used in the design of the breadboard transmitter units. Deviations must be made, however, in the interest of attaining the primary goal of developing and demonstrating the high-efficiency visual final amplifier design.

3.1.5 Mechanical Design

A breadboard layout of the form shown in Figure 3-2 was selected as appropriate for the present breadboard application. The cavities and other transmitter components are to be mounted on an aluminum plate which also serves as the heat sink for conduc-

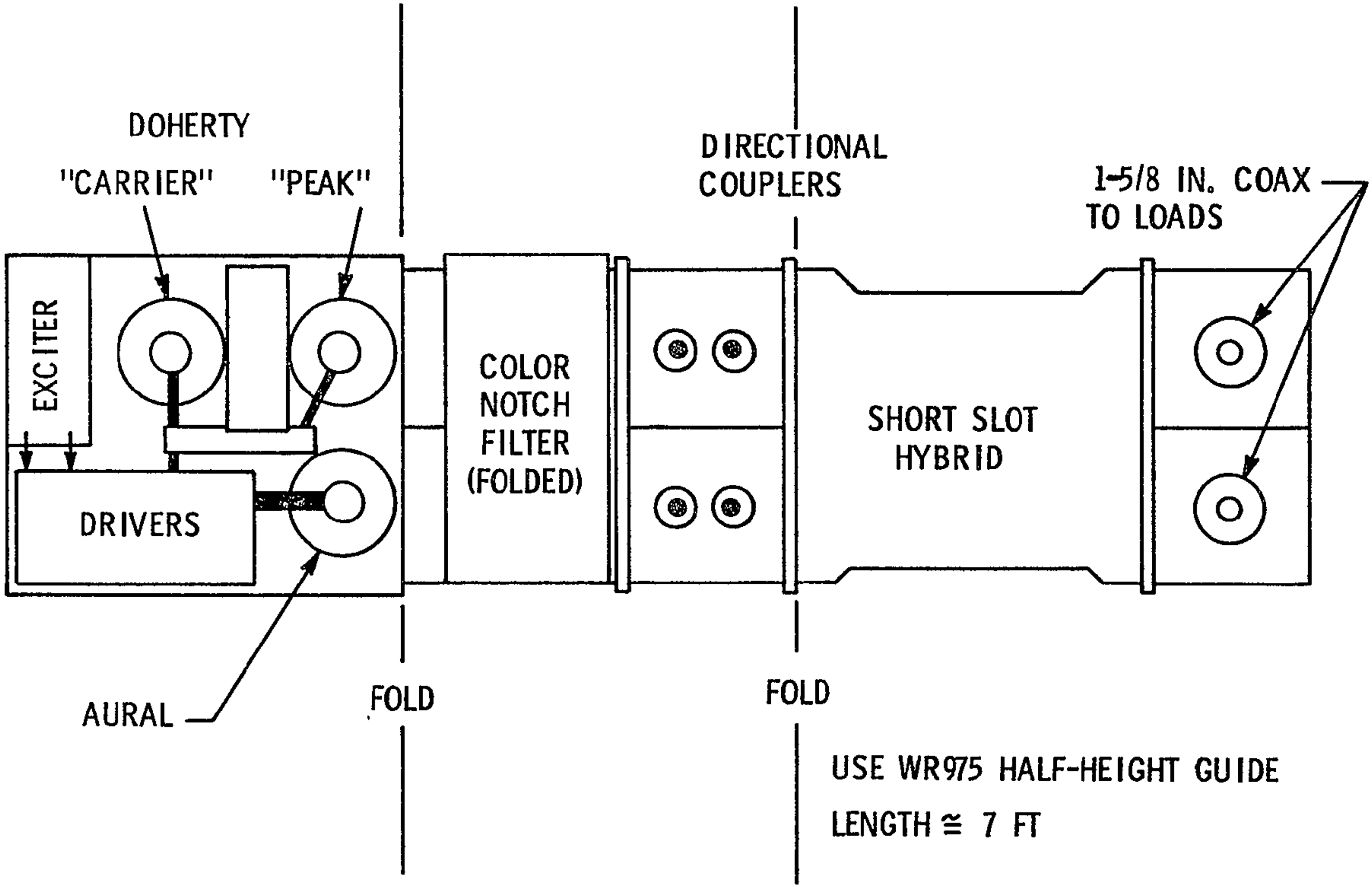


Figure 3-2. Breadboard Transmitter Mechanical Layout

tion cooling of these components. The amplifier outputs are connected to a dual wave-guide assembly which contains a color notch filter, rf monitoring directional couplers, hybrid diplexer, and transitions to dummy loads. Although the assembly is rather large, it is low in height and could be folded into a compact cubic package measuring about 2 feet on a side.

3.1.6 Monitor and Protective Circuits

In the monitoring and protective area the following features are included:

- plate current overload trip for all tubes
- grid current overload trip for all tubes
- crowbar protection for the Y1498 tubes
- VSWR trip for the Doherty amplifier

Other control logic functions are provided by the test power supply. Due to their anticipated high reliability, vacuum spark gaps were selected as an optimum device for protecting the Doherty amplifier tubes. These gaps are rugged mechanically and electrically and will have little or no degradation except when actually fired during tube faults. No significant standby power is consumed because these gaps contain no heater, keep-alive, or other element which must be operated continuously in anticipation of the occurrence of a fault.

3.1.7 Controlled Carrier Circuit

The operating parameters of the required controlled carrier circuit is described later in Sections 3.6 and 5.6. A small resistor in the B-lead provides an indication of current flow; an average current demand above the threshold will reduce the RF drive. The controlling circuit thus involves an amplifier following the current sampling resistor, a threshold circuit, and a drive circuit to vary the attenuation of the RF input signal by suitable diodes. The drive variation is such that the total dc power required by the linear RF output amplifier is constant for all pictures darker than that corresponding to the average gray threshold level.

3.2 VISUAL CHANNEL AMPLIFIERS - TASK 2

3.2.1 Driver Stage

The driver stage in the visual amplifier chain is a Class B linear amplifier, using a Machlett ML-8534 planar triode tube to obtain a nominal peak output of 125 watts to drive the high power Doherty amplifier. The driver has been designed and fabricated, and preliminary tests have been made. The output coupling loop appeared to provide improper coupling to the load, and is being redesigned. With the non-optimum coupling, the driver was operated at levels up to 85 watts of rf output power.

The grounded grid driver circuit is shown in Figure 3-3. The grid is at dc ground as well as rf ground, thus assuring minimum rf feed-thru and also a minimum multipactor likelihood in the output cavity. The cathode circuit is resonated by a low impedance short-circuited transmission line of less than one quarter wavelength. A detailed diagram of the amplifier configuration can be found in Section 5.2.1. The anode circuit is also a quarter-wave short-circuited coaxial line; its impedance was chosen as a design compromise between a small diameter center conductor line to minimize the loaded Q and a large center conductor line diameter to minimize the temperature drop between the anode and the cavity surface. A second cavity is coupled to the first by an iris, thus forming a double-tuned circuit which will provide the required bandwidth.

The computed performance is as follows:

Output Power	137 watts max.
Drive Power	6.37 watts
Gain	13.3 dB
Efficiency	64%
Input Impedance	75 ohms
Load Impedance	4050 ohms

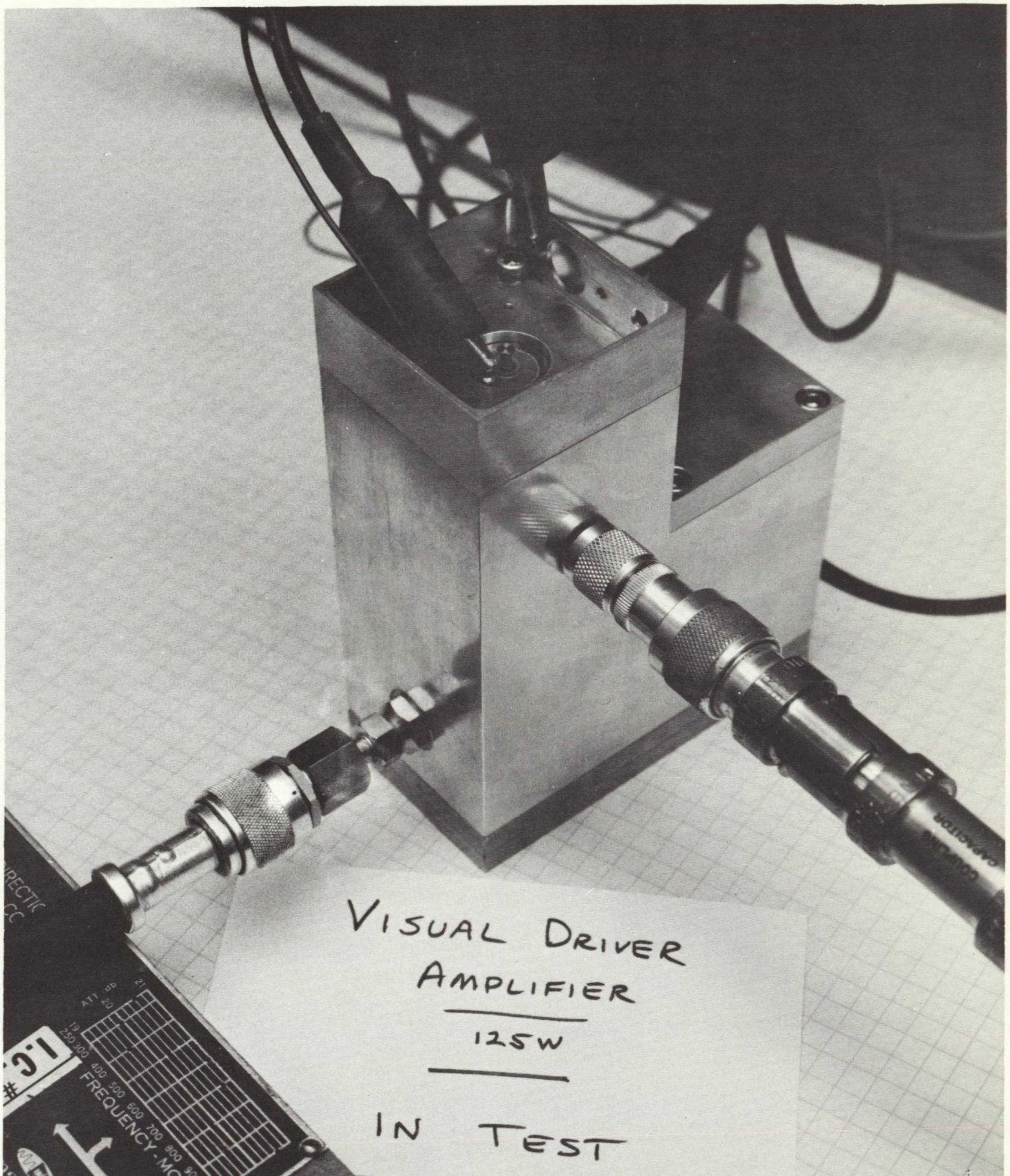


FIGURE 3-3. VISUAL DRIVER AMPLIFIER

Plate Voltage	1200 volts
Grid Bias	-15 volts
Plate Current	168 ma
Grid Current	37.5 ma
<u>Cavity with Tube:</u>	
Loaded Q	72.5
1 dB bandwidth	
- single tuned	5.9 MHz
- double tuned	18.6 MHz

The cavity has been cold tested. The resonant frequency of the cathode line was initially 875 MHz but it has been decreased to 821 MHz by the addition of a tuning capacitor between the case and cathode line near the cathode flange. The plate line resonated initially at 819 MHz, which is too close to the operating frequency to allow for an added tuning adjustment to compensate for manufacturing variations among tubes. The plate line impedance will be raised slightly in order to reduce the resonant frequency. Then a slug tuner can be used to adjust the tuning precisely to the proper value.

Initial rf tests indicate that there is no detectable rf leakage for either the input or the output cavity. The input impedance match yielded a VSWR of 1.8:1; however, the output loop reactance was excessive and prevented optimum coupling. As a result only 85 watts have been obtained so far with 7 watts of input drive and at a 1.2 kV anode potential. The output coupling loop is being modified for further tests.

3.2.2 Doherty Power Amplifier

This task is to design Doherty high-efficiency visual-channel amplifier with a 5 kW sync peak output. Fabrication and testing are scheduled to commence in the near future. Details on the principle of operation of the Doherty amplifier may be found in Reference 2 and in its references; the resulting amplifier circuit is in Figure 3-4. The circuit uses two L-54S/Y1498 tubes with the necessary intercoupling; the diagram

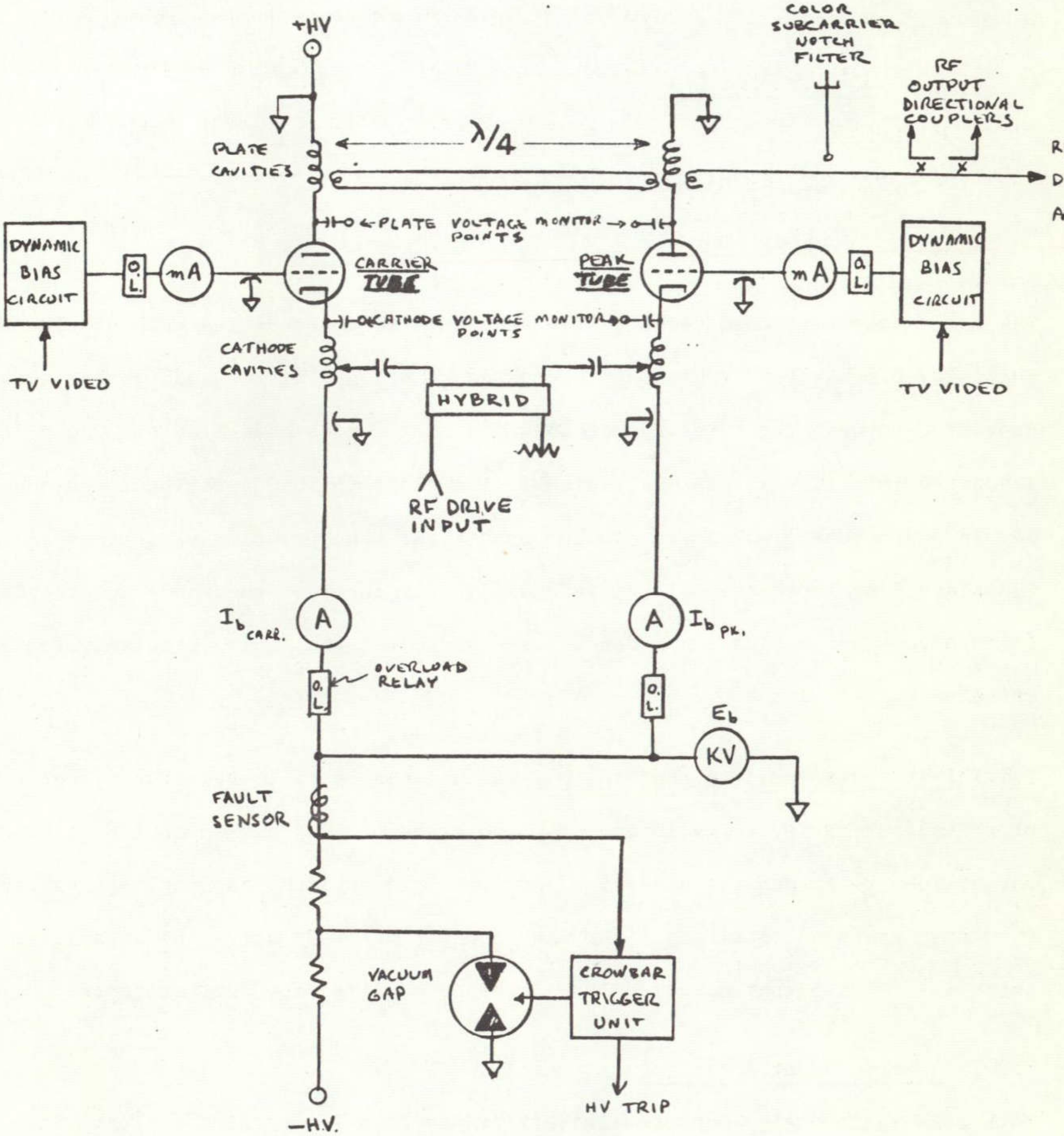


FIGURE 3-4. DOHERTY SCHEMATIC DIAGRAM

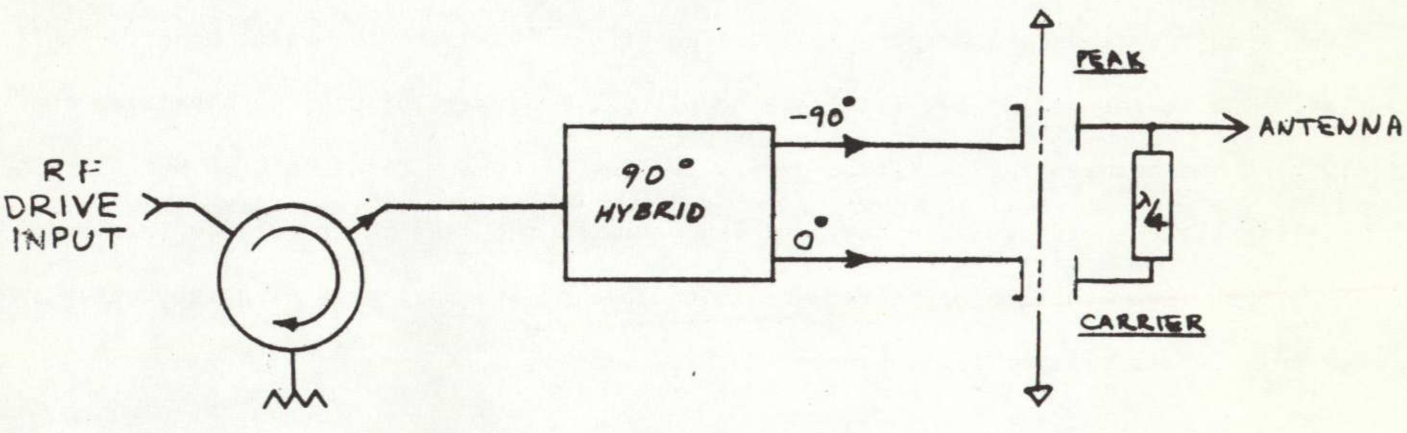
shows the equivalent lumped circuit constants for the plate and cathode tuned circuits, although cavities and coaxial lines are used in the actual circuit.

This circuit introduces two principal design innovations into the basic Doherty amplifier. One is the use of low impedance couplings, necessary at UHF, both between the cavities and between the peak tube cavity and the antenna. Tests on a 30 MHz simulator[2] modeling the UHF cavity circuitry have demonstrated the feasibility of low impedance couplings. The other major difference is the use of grounded grid circuitry which is the only feasible amplifier approach at UHF.

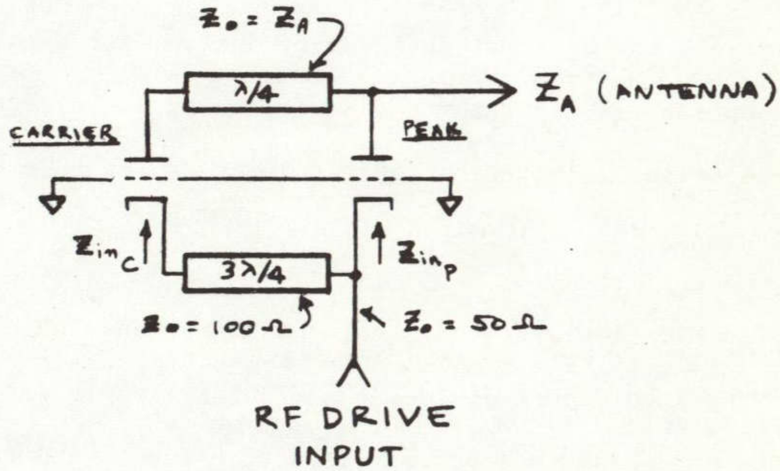
The plate circuit cavities will be the same as those of the aural channel final amplifier, discussed in section 3.3. Output coupling will be accomplished by means of an iris to a WR975 half height waveguide (discussed Section 3.4.1). The amplifier is tentatively a dc grounded anode type, so the crowbar protective circuit is included in the cathode dc circuit of Fig. 3-4.

Some modifications to the aural tube cavity design will be necessary in order to incorporate two couplings in the peak tube anode cavity. Electrical design of the cavity to waveguide coupling is based on radial cavity design procedures[8] and coupling iris design procedures.[9]

Tests on the 30 MHz simulator and other considerations indicated unique designs are required for the input power divider/phase shift circuit and for dynamic control of amplifier tube grid bias to suppress distortion levels and to achieve a high efficiency. Two approaches to input power division were considered, as indicated in Figure 3-5. One approach is to use a directional coupler type of power splitter which provides the required 90° phase shift between carrier tube and peak tube inputs. This is included in Figure 3-4, and is the type for initial implementation. The alternate approach is to use a $3\lambda/4$ transmission line section between cathodes for impedance matching and phase shift control, with the input signal applied to the peak tube cathode.



HYBRID DIVIDER CIRCUIT



POWER SPLITTER CIRCUIT

Figure 3-5. Input Circuits for Doherty Amplifier

A dynamic grid bias circuit will vary the grid biases as a function of the instantaneous rf drive level. This is desirable in a Doherty amplifier for several reasons:

- the amount of drive on the carrier tube causes saturation at carrier level (½ peak voltage)
- beyond this point, efficiency can be increased slightly if tube grid bias is changed to operate in the class C region
- as the drive is increased, the drive signal at each grid does not increase linearly due to changing impedance levels as the grids begin to draw current
- by varying the bias accordingly, non-linearities can be reduced.

The dynamic bias circuit is shown in Figure 3-6. The circuit can be adjusted to increase the bias on the Class B carrier stage such that it becomes a Class C amplifier near the peak signal; the variation of bias with signal level for this stage is shown in Figure 3-7. The same circuit can be used for the Class C peak stage, although here the bias must be decreased with increasing drive as indicated in Figure 3-7. Thus, the peak tube starts conduction at the one-half peak drive voltage point, and then decreases its bias such that both stages are operating in essentially the same condition at the peak signal.

Fabrication will begin shortly. The cavities will be fabricated and tested with the Y1498 tubes. Then the input circuit and the two dynamic bias circuits will be designed to match requirements, and the assembly will be tested to determine compliancy with EIA standards and the requirements of Section 2.3.2-2.

3.3 AURAL CHANNEL AMPLIFIER - TASK 3

3.3.1 General Design

The overall transmitter design requires a 500 watt FM aural channel amplifier to supplement the 5 kW AM visual channel amplifier chain in the overall TV transmitter. The amplifier uses a single Y1498 tube (production version of the GE type L-64S) in a Class C circuit. The amplifier has a three-quarter-wave coaxial input line cavity and a quarter-wave coaxial output cavity, using a dc grounded anode and rf grounded

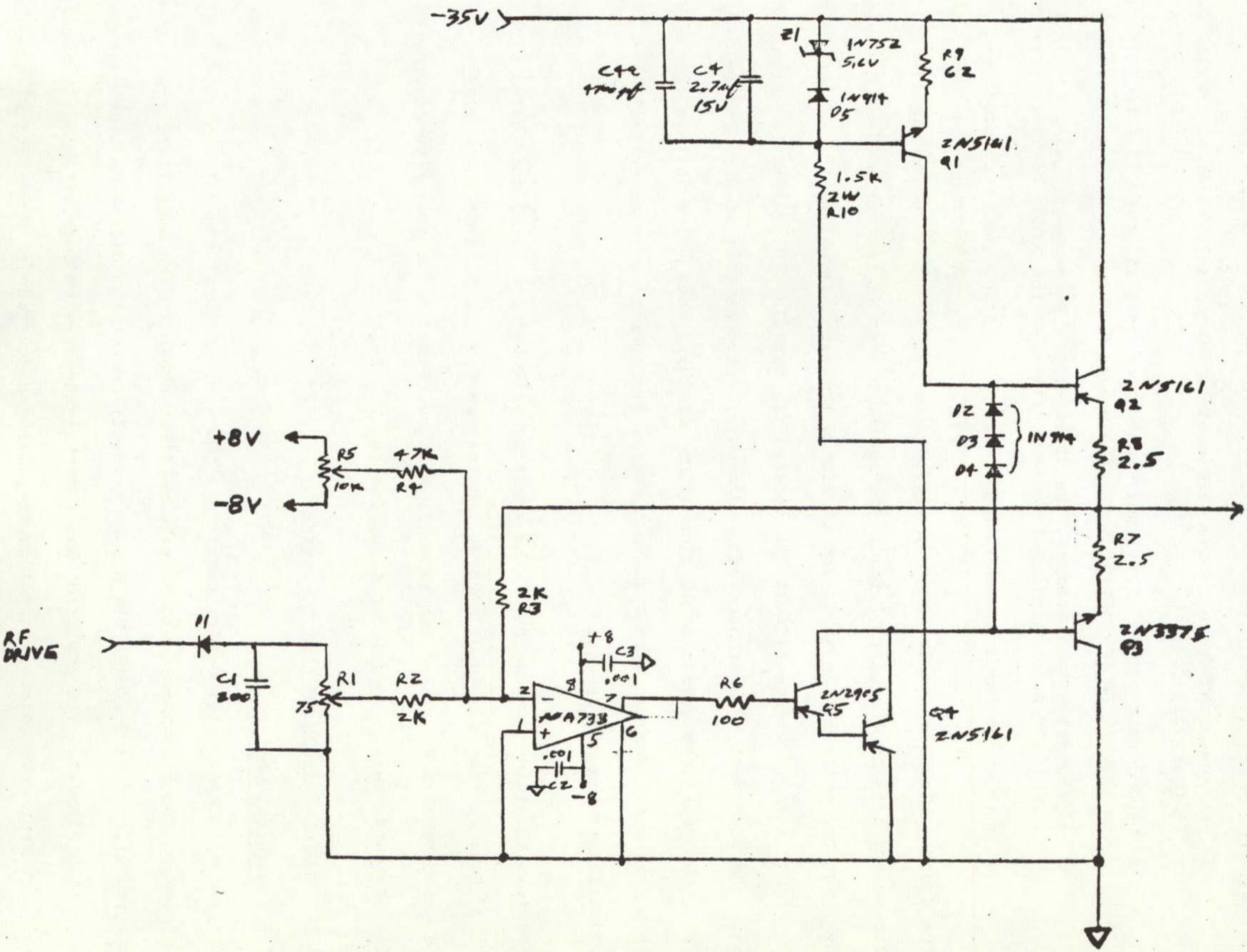


FIGURE 3-6. DYNAMIC BIAS SCHEMATICE FOR DOHERTY AMPLIFIER

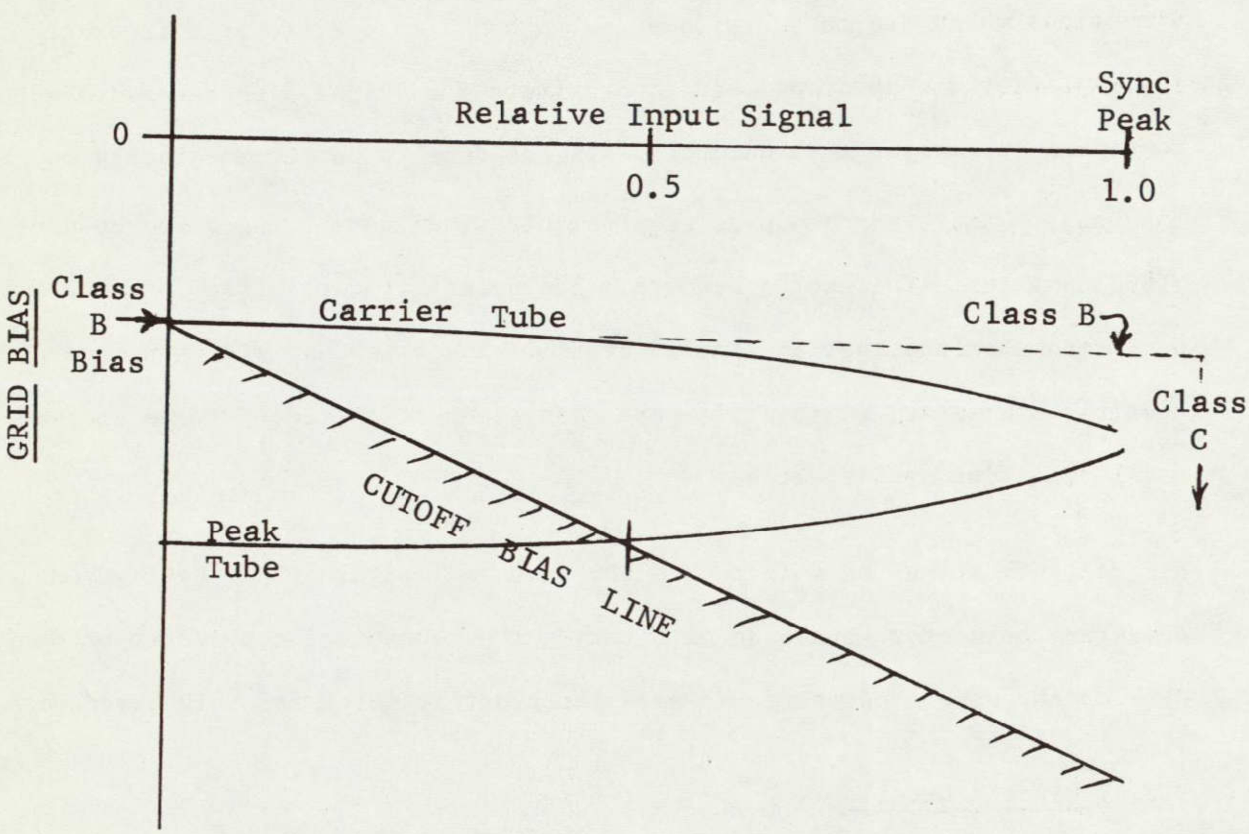


FIGURE 3-7

BIAS VARIATIONS ON DOHERTY AMPLIFIER TUBES

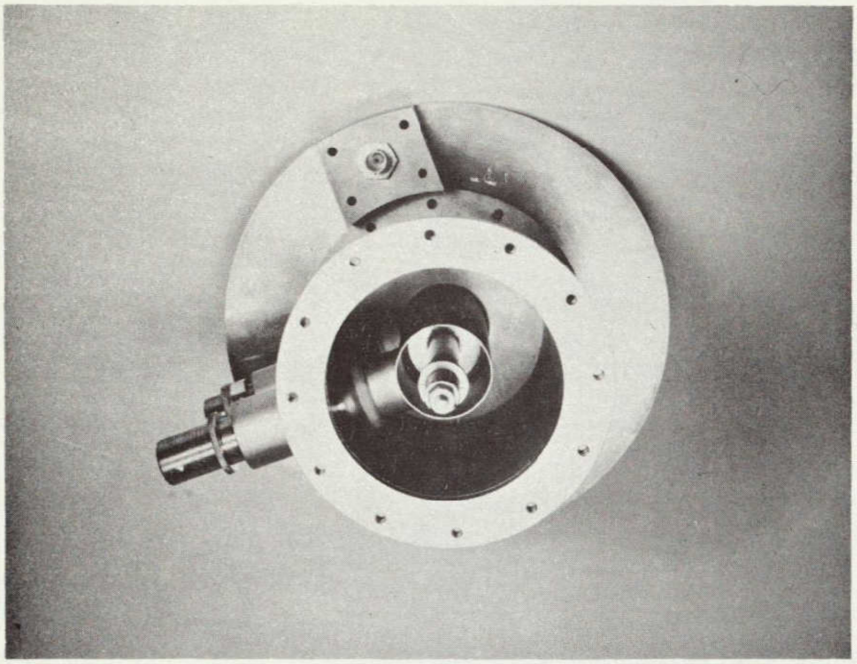
grid circuit. Figure 3-8 shows two views of the resulting amplifier; a detailed cross-section diagram of the amplifier is shown in Figure 5-7 of Section 5.3.

The amplifier will use a dynamic grid bias circuit similar to that of the Doherty amplifier (Figure 3-6); its purpose here is only for protection of the grid against overloads. Tests of the amplifier without operating power applied have been conducted. Testing has not yet been completed, however, primarily due to some changes in cavity dimensions which are to be implemented in order to operate at a frequency of 829.75 MHz. The amplifier was developed with approximately a 50 MHz 3 dB-bandwidth,which is considerably greater than needed. This was done to permit the cavity to easily meet the Doherty amplifier bandpass requirements, thus permitting a common design for all Y1498 cavities. The excess bandwidth has no significant effect on over-all system performance except that the amplifier will show a few dB less gain than ultimately possible. However, it is still more than adequate for the purpose and will meet the aural amplifier specifications.

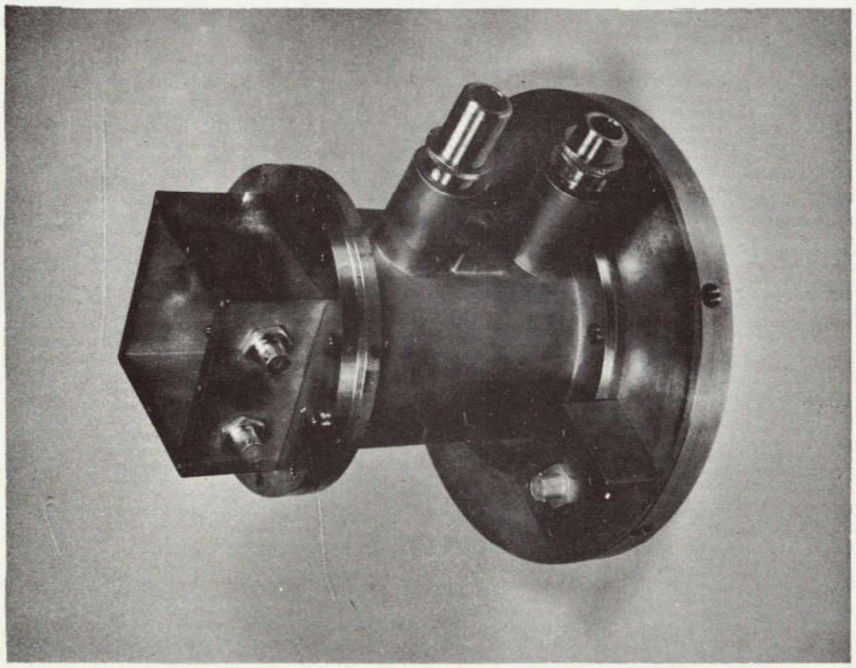
No great effort was made to reduce the size and weight of the cavity; ease of adjusting operating parameters and ease of altering the mechanical configuration during development were considered the more important feasutes for this breadboard model.

3.3.2 Circuit Details

Perhaps the simplest circuit applicable to planar triodes like the Y1498 tube at UHF is the grounded grid circuit employing coaxial resonators. The tube inter-electrode capacitances load the resonant transmission line sections, thus causing the lines to resonate at a frequency lower than that for which they are exactly a quarter wavelength (or $3\lambda/4$). To accommodate this effect, the cavity is designed with its physical length less than $\lambda/4$, just enough so the frequency is at the desired value. A $\lambda/4$ radial cavity has been selected for use between the plate and the grid, and a $3\lambda/4$ coaxial cavity between the grid and the cathode. The bandwidth reduction effect of



Input Cavity



Assembled

FIGURE 3-8. AURAL CHANNEL AMPLIFIER

the $3\lambda/4$ cavity (Section 5.1) is not critical in the low Q input circuit.

Necessary dc operating voltages require that sufficient insulation be used, and the insulation should be compatible with the rf circuit. The large value of dc blocking capacitance between grid and cathode and between cathode and anode can best be implemented with a folded cathode line configuration as shown schematically in Figure 3-9, or in detail in the amplifier cross-section in Figure 5-7 of Section 5.3. The folding approach permits the cathode/anode bypass to be located physically at the foldpoint of the folded line. The grid bypass is also conveniently located at the grid flange.

3.3.3 Circuit Operation - Design Objectives

An aural channel amplifier has been designed and fabricated to operate with the following characteristics:

Operating frequency	829.75 MHz
Bandwidth	
0.5 dB	15 MHz (100 kHz min.)
3.0 dB	50 MHz
Plate Voltage	1500 volts
Operating grid bias	-20 volts
Plate current	0.5 amps
Grid current at full rf output	0.1 amp
Drive Power	5 watts nominal
Plate power	750 watts
Heater power	26 watts
RF power output	500 watts nominal
Plate efficiency	67%
Net efficiency	64%
Input VSWR	1.8

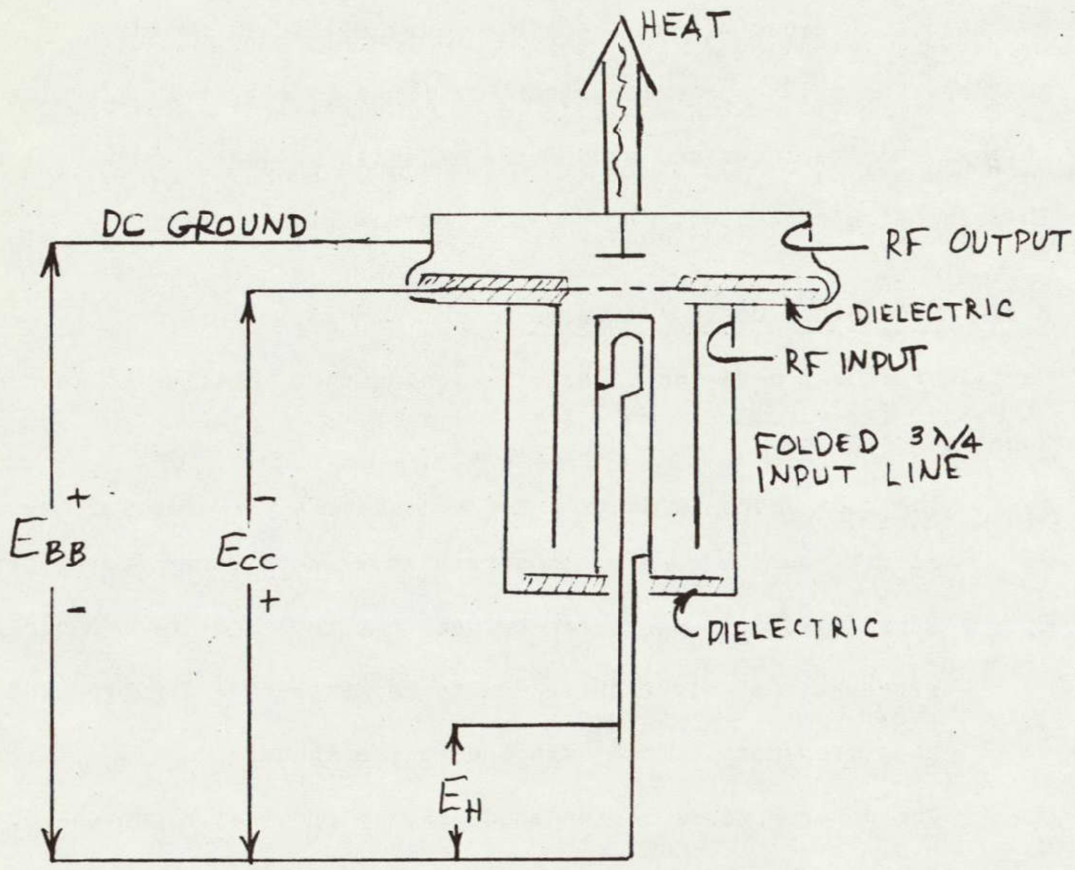


FIGURE 3-9. SCHEMATIC OF FOLDED CAVITY AURAL AMPLIFIER

The usual problems were encountered in the circuit. Both cavities had to be trimmed to meet the frequency requirements. Following this, however, an unusual amount of feed-thru from the input cavity to the output cavity was observed. Since the tube was cold, the cause of the feed-thru was difficult to identify. After extensive testing, the grid bypass capacitor was found to act as a $\lambda/4$ line, the rf passing through the insulator and around the grid flange (see Figure 3-9) to the anode cavity. This is being corrected, after which tests will be performed.

3.3.4 Mechanical Design Features

Certain features were included in designing the amplifier to meet specifications. Some of these are:

1. The tube anode is dc grounded and thermally isolated from the cavity structure, permitting the cavity to operate at a lower temperature than the anode.
2. Some flexure is permitted between the tube and the two cavities so as to relieve stresses that might arise due to separate mountings for the cavity and the heat transport system attached to the anode.
3. The upper surface of the anode cavity provides a convenient mounting surface and heat transfer interface.
4. A copper flange soldered directly to the tube's grid contact surface provides a larger surface for grid heat flow to the cavity, which then conducts it to a final sink. The bypass capacitor insulation, through which the heat must flow, will also have a lower temperature differential if it has a large surface.
6. No dangerous voltages are accessible when the cavity is assembled.
7. The over-all structure is compact and rigid.

3.3.5 Testing

Initial tests on the amplifier will use a coupling loop to extract power from the anode cavity. For the final configuration, an iris will be cut in the outer wall for

coupling the anode cavity directly to the output waveguide.

Tests on a cold anode to grid cavity resonator were conducted to determine dissipative loading of the tube on the tank circuit. The Q of the test cavity was measured, and it was found to increase by factors of about 2.7 to 5.3 (Q_u value as high as 900) after polishing and plating of tube electrodes and cavity parts.

3.4 RF COMPONENTS - TASK 4

3.4.1 <u>High Power RF Components</u>

Several RF components are required in a television transmitter to inter-connect the high power amplifier outputs with the antenna and to provide other functions such as filtering, power monitoring, diplexing of the aural and visual signal outputs, and harmonic suppression. Harmonic suppression is not considered necessary for this non-radiating breadboard system since harmonics will not appreciably affect fundamental frequency operation. The question of potential breakdown in harmonic filters will be evaluated in Sections 3.7 and 5.7.

The components which were designed, fabricated, and tested in this task are:

Color Subcarrier Image Rejection Filter

Incident and Reflected Wave directional couplers (power monitoring)

3 dB Hybrid (GE Component)

Dual Waveguide to Coaxial Transitions

The RF components for the breadboard transmitter are shown in a sketch in Figure 3-10. The requirements for these components were included in Section 2.3.4; the equipment designed and fabricated to meet these requirements is discussed here. Photographs of the the rf assembly are shown in Figure 3-11.

3.4.1-1 Color Notch Filter

The color subcarrier image notch filter used for the breadboard transmitter is a top-wall coupled single cavity type which conforms to current TV design practices and was

ITEM	DESCRIPTION*
1.	Color image notch filter/ directional coupler assembly
2.	Hybrid, 3 dB sidewall coupler
3.	Adapter, dual, waveguide to 1-5/8" EIA coaxial line, 50-ohm

*Note-All waveguide connections are dual flange, 1/2-height WR975 waveguide.

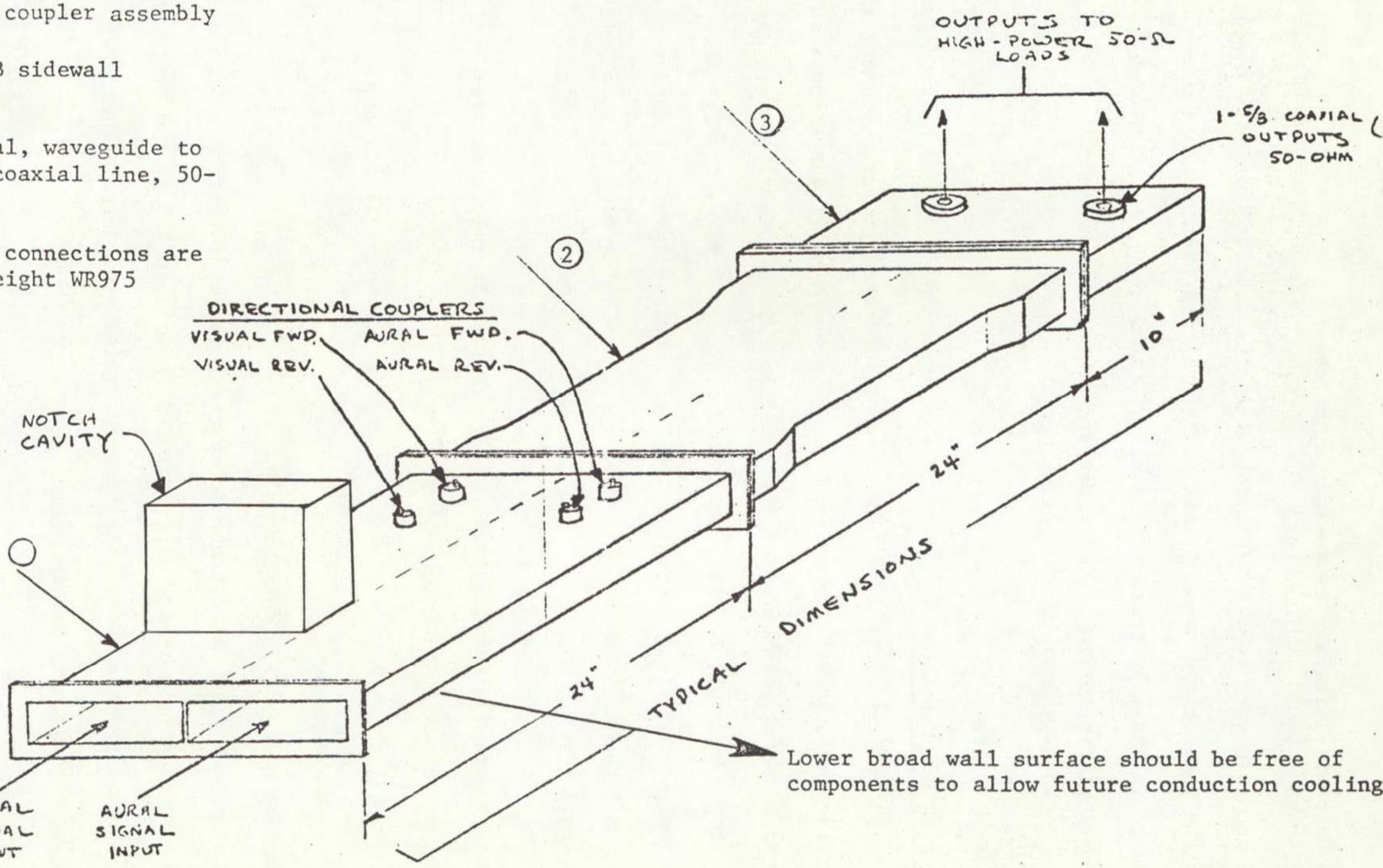


Figure 3-10. Waveguide Assembly for TV Transmitter Breadboard Setup

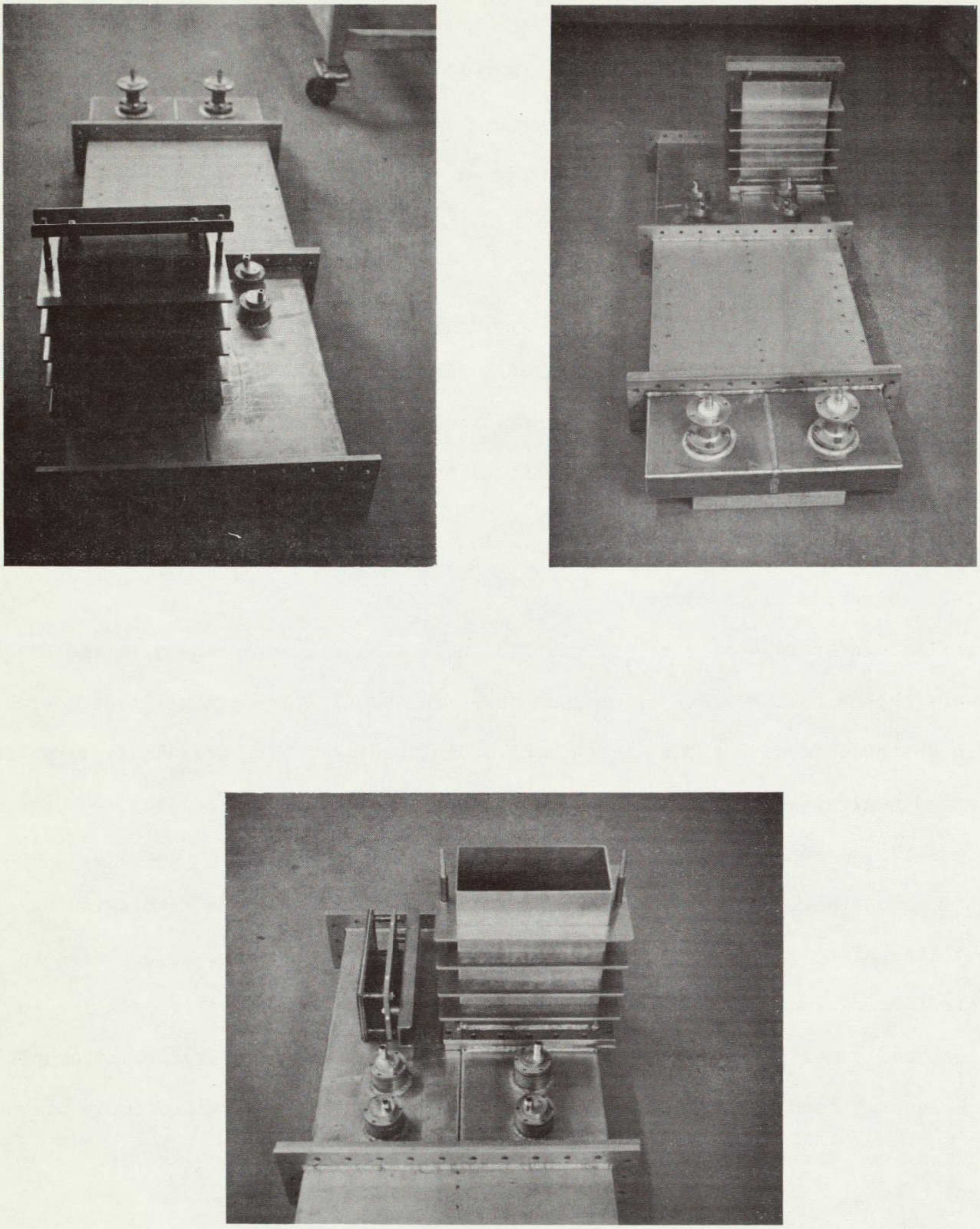


Figure 3-11. Fabricated Waveguide Assembly

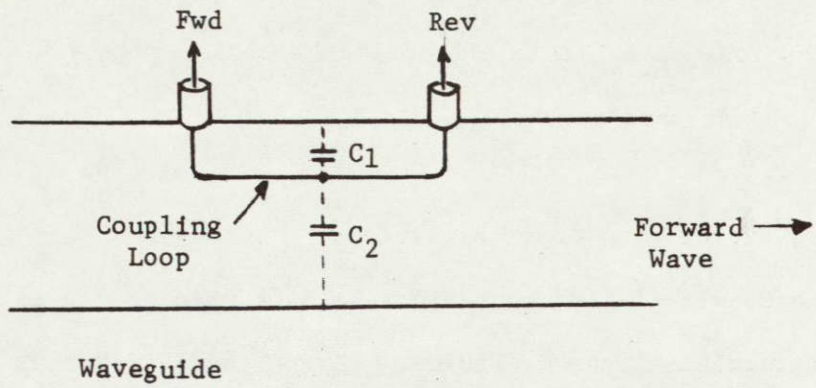
found to be adequate[2]. This filter is a high-Q type tuned to 821.67 MHz; a calculation has indicated that the Q should be of the order of 18,000, which is attainable with a WR975 dimensioned cavity. The calculated loss at the resonant frequency is then of the order of 0.1 dB, and rejection of the unwanted signal is 20 dB. The device is shown attached to the waveguide assembly in Figure 3-11; note that it has been left unfolded for the breadboard design. Tests made on the device indicated it operates within the loss and rejection specifications. Measurements showed the insertion loss to be less than 0.1 dB, rejection more than 20 dB, and VSWR of 1.23. The latter suggests tuning will be necessary in the assembly. These data include the directional couplers discussed in the next section since the filter and directional couplers were assembled as a unit.

3.4.1-2 Directional Couplers

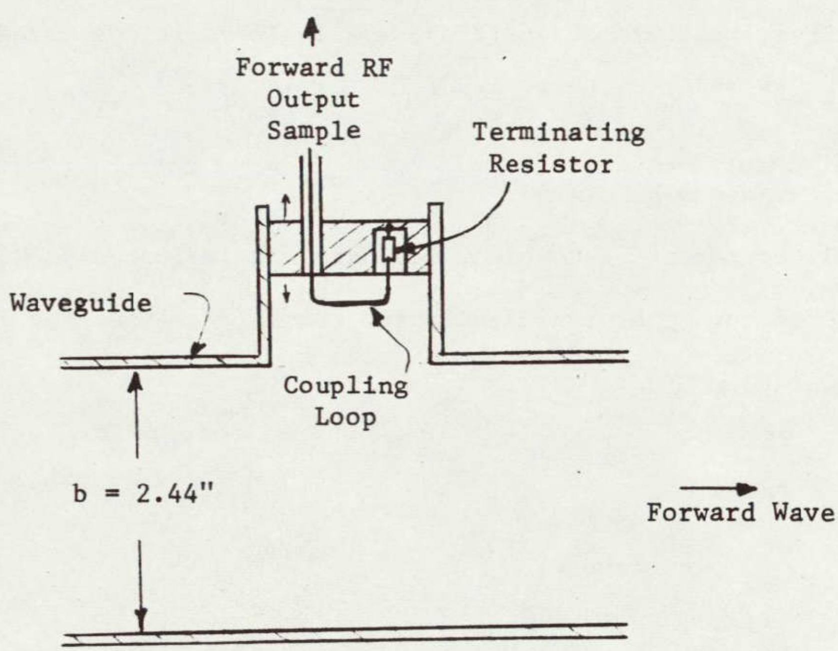
The reflectometer type directional couplers have adequate performance in the UHF band, and were chosen on the basis of compactness. The sensitivity of this type increases by 6 dB per octave, but the narrow band of interest for this breadboard makes this variation negligible. An illustration of the basic form of the coupler is shown in Figure 3-12. A small loop is introduced into the waveguide, which couples to both the magnetic and electric fields by virtue of its orientation, and is terminated by a coaxial output line of Z_o impedance. Two couplers are used in each channel, one each to monitor forward and reverse powers. Requirements for these couplers detailed in Section 5.4.1; measurements on the final couplers indicated -50 dB forward coupling, -40 dB reverse coupling, and 30 dB isolation, all of which are sufficiently close to specifications for this program. Insertion loss is considered negligible.

3.4.1-3 3-dB Hybrid

This component is included in the test because of its availability as a loan item from another program. The tests could also be performed with the visual and aural output signals entering separate absorptive loads. However, the 3 dB hubrid combiner will



(a) Basic Reflectometer Type Directional Coupler



(b) Arrangement of Couplers Used in the Breadboard Transmitter

FIGURE 3-12. DIRECTIONAL COUPLERS

provide some indication of the load interaction effects which might occur with a diplexer in the system, and each of the two outputs will have half of the total aural and half of the total visual signal powers. The hybrid is shown in the photographs of Figure 3-11. Its loss is negligible ($<$ 0.1 dB), coupling is 3.0 dB, isolation is 33 dB, and VSWR is 1.03 at band center.

3.4.1-4 Waveguide-to-Coax Transitions

Coaxial loads with 1-5/8" connectors will be used in the tests. Two transitions are used to interconnect the waveguide lines and the 1-5/8" coax lines which go to the loads. The loss in a transition was measured to be less than 0.1 dB; each of these transitions can easily handle half the 5.5 kW peak power that is in each of the output waveguides of the RF system. The transitions are included in the waveguide assembly, in Figure 3-11. The VSWR was measured to be 1.03.

3.4.1-5 Assembly

With all components assembled, measurements indicated VSWR's, after additional tuning, of 1.10 in both the visual and aural channels ; insertion loss is estimated to be about 0.1 dB.

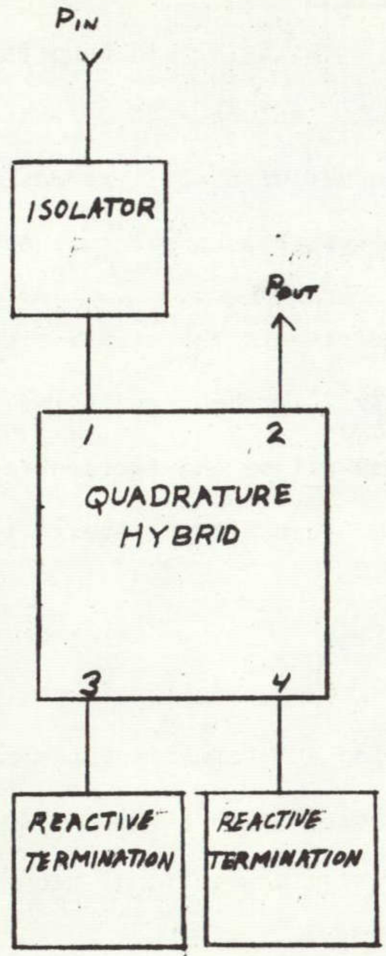
3.4.2 Vestigial Sideband Filter

The response requirements of a vestigial sideband filter for television transmission, shown previously in Figure 2-3, include a 20 dB skirt drop-off in a 0.5 MHz interval. This skirt requirement can be met with a filter design using the phase sensitive properties of a 3 dB quadrature hybrid as shown in the block diagram of Figure 3-13.

The quadrature hybrid is sensitive to the relative phase and magnitude of the termination at each of its 3 dB ports. If the signals reflected from both terminations are in-phase, the hybrid will pass all of the incident energy. If the two reflected signals are 180° out of phase, then all the energy is reflected back to the source and there is no output.

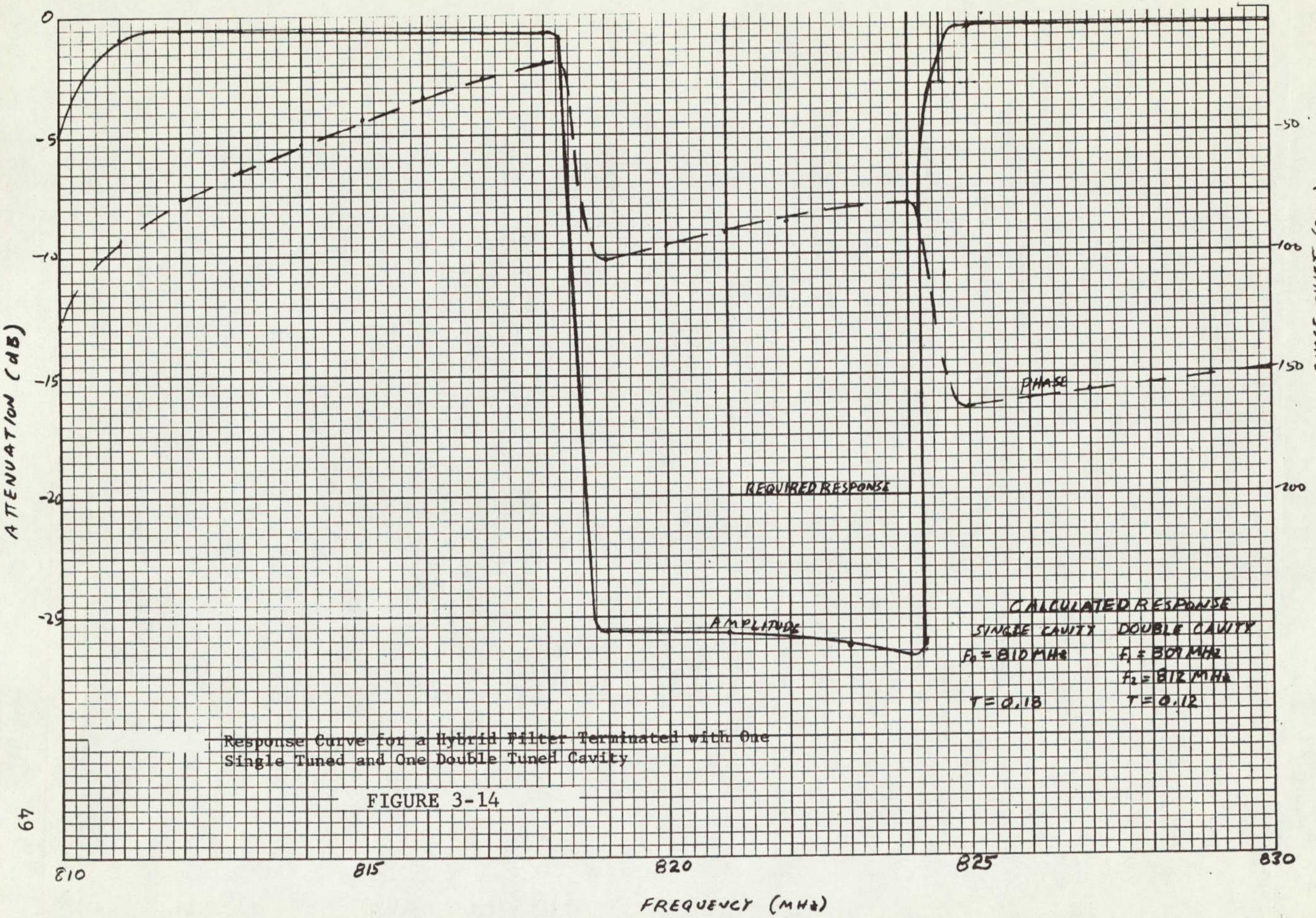
The vestigial sideband filter makes use of this characteristic to yield a bandstop filter response with very steep skirts. Since the phase of a resonator changes much more rapidly than its amplitude, a much steeper skirt is obtained from the phase type filter than can be obtained using conventional techniques.

The filter configuration which provides acceptable theoretical performance uses one double-tuned and one single-tuned cavity as terminations on the hybrid, as shown in Figure 3-13. Figure3-14 illustrates the computed filter response for the selected configuration and includes the ideal response curve for comparison. The filter, which must be capable of dissipating up to 5 watts (i.e., half the maximum input power), is fabricated of stripline; Figure 3-15a shows the conductors before final assembly and Figure 3-15b displays the completed final assembly, the dimensions of which are 6" x 10" x 3/4".



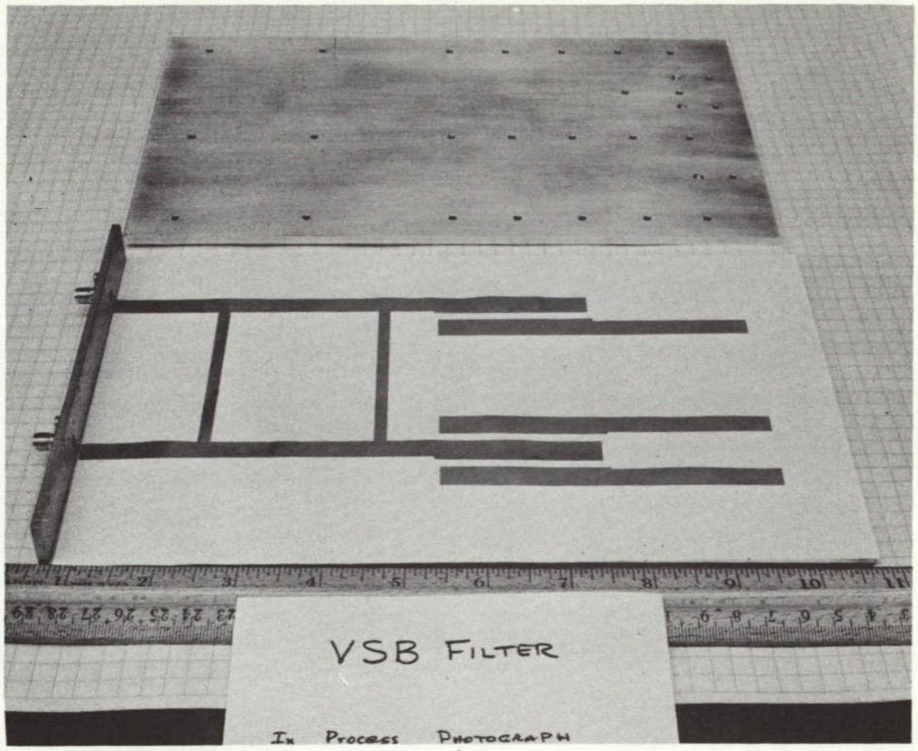
BLOCK DIAGRAM OF A VESTIGIAL SIDEBAND FILTER

FIGURE 3-13.

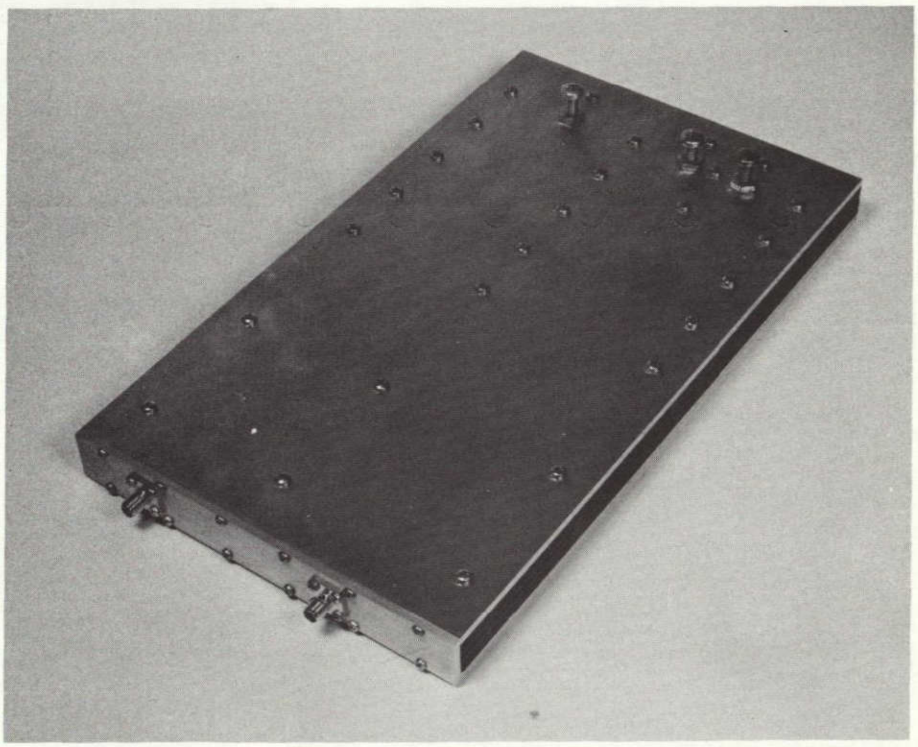


Response Curve for a Hybrid Filter Terminated with One Single Tuned and One Double Tuned Cavity

FIGURE 3-14



(a)



(b)

FIGURE 3-15. VESTIGIAL SIDEBAND FILTER

The ground planes are made of 1/8" aluminum plate while the intervening space is filled with four 1/8" polystyrene plates; the stripline structure employing one mil brass shim stock is centered in the sandwich. In the space version, the polystyrene will be replaced with PPO material.

Initial tests on the filter have shown the rejection band to be broader and the slope of the skirts to be less than predicted. Measurements are being made on the resonator Q's to determine the advisability of using silver stripline to get the actual performance to more closely approach the theoretically expected performance.

3.5 MONITOR AND PROTECTIVE CIRCUITRY - TASK 5

3.5.1 Requirements of Circuitry

Performance monitoring is required for those devices and components of the transmitter where electrical failures (due to shorts, voltage breakdown, etc.) are most likely to result in a catastrophic system failure if unchecked. Signals from the monitoring devices can be utilized to actuate protection and control circuitry to prevent permanent damage to critical components like the final power amplifiers and the power conditioner subsystem. By proper and instantaneous protection and control action, permanent damage to these components will be avoided and they can operate again after the fault is cleared or eliminated. In addition, the laboratory equipments associated with the transmitter development and test phases of this program do not normally incorporate many of the features necessary for adequately protecting the components of the breadboard transmitter.

Specific circuitry required includes an electronic crowbar for dc protection, an rf drive switch, sensors for both dc and rf faults, and logic circuitry to effect protective action when a fault occurs. A dc breakdown, which would endanger the final amplifier stage if within a tube, or the power conditioner if external to the tubes, would cause the crowbar to be triggered, shorting the power supply output to ground; at the same time, the logic circuit would open the prime power input bus to the conditioner and turn the power off. In the case of rf breakdowns in the waveguide assembly, the rf drive is removed. After a suitable time delay, the logic circuit may turn the equipment on again, depending on the specific nature of the fault. Parameters to be monitored include plate voltages and currents, grid currents, RF input and output signals in both the forward and reverse directions, stage efficiencies, and gain and phase distortions.

To protect the dc circuitry and components when a breakdown occurs, the entire elapsed time involved must be less than a few microseconds from time of fault until the energy

is diverted. A small amount of fault energy (< 10 joules) is usually beneficial to the tube since it helps clear the flaw if caused by a metal whisker inside the tube. The crowbar logic circuitry also sends a signal to remove the prime power supply voltage. During this shutdown process time, the crowbar device must divert fault energy and remain a virtual short circuit across the load. If the crowbarring action ceases before the main power source is disconnected and all storage devices are discharged, the possibility exists of a voltage build-up sufficient to cause a recurrence of the arc.

For the VSWR protective circuit all that is necessary is a threshold detector that can operate on a rectified sample of the reflected RF power. When the threshold is exceeded (preset at a nominal maximum safe level) a signal is generated to remove RF drive and high voltage from the tubes.

3.5.2 Design Approach

The selection of the crowbar device considered size, weight, ruggedness and reliability as well as performance. All circuitry is solid state; the design of the crowbar and associated circuitry was based on a need to operate under varied power supply and transmitter conditions.

Several assumptions were necessary in the crowbar design. An assumption of the size of the energy storage elements (inductor, capacitor) in the filter of the power conditioner was necessary to determine the size of the crowbar device to be used. Also, maximum values for parameters such as plate voltage and plate current were required in order to place an upper limit on circuit requirements.

A vacuum spark gap was selected for the high power visual amplifier stage. The trigger, logic and control circuitry was designed using solid state components and constructed according to standard printed circuit board techniques. Packaging and mechanical design were given only minor consideration since the unit was to be a breadboard design. Design specifications for the required 30 KV trigger unit to fire

the vacuum spark gap were investigated and a commercial unit specifically designed for the purpose, was purchased. After the initial design, the requirements for the circuitry were reviewed and minor design changes were incorporated to achieve an integrated design. Upon completion of construction the unit was thoroughly tested.

3.5.3 Protective Circuit Designs

The crowbar circuit, Figure 3-16, provided fault protection entirely adequate for high power direct broadcast satellite transmitters. This unit performed quite satisfactorily in discharging 72 joules (9μf @ 4KV) of stored energy during preliminary testing. The transmitter breadboard should operate well with this crowbar, although it will oprate with 2.5 KV across 45 μf or at 140 joules. The delay time between initiation of the fault and the firing of the crowbar is less than 1.0 μsec and could be reduced further if necessary, or could be designed to be varied. The total discharge energy in the protected circuit (tube) was calculated to be well below the 5 joule value estimated to be detrimental to tube operation.

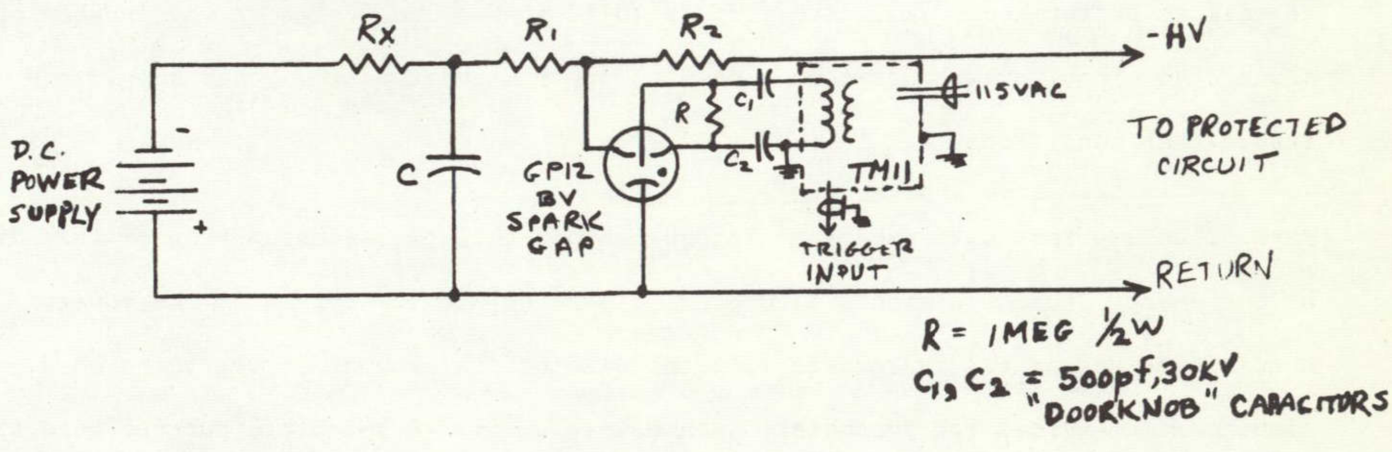


FIGURE 3-16. CROWBAR CIRCUIT

The VSWR trip circuit circuit, discussed further in Section 5.5.3, will operate well over a broad range of RF input levels thus allowing maximum flexibility in the further design of RF circuitry for monitoring reflected power. The trigger, logic, and control circuitry are also discussed in Section 5.5, and showed adequate performance. The

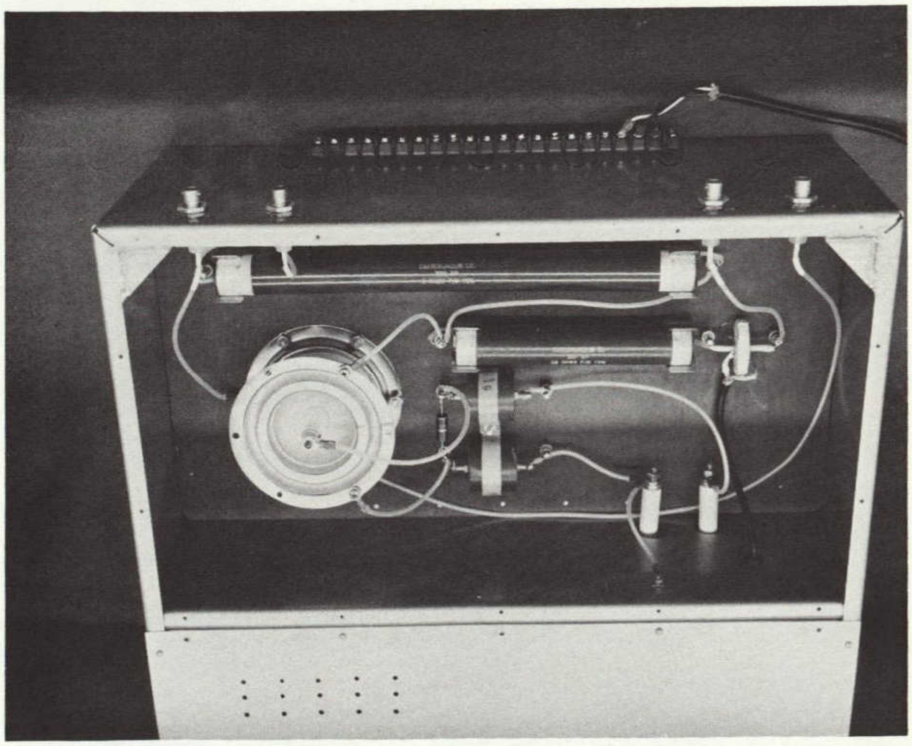
complete unit is shown in Figure 3-17; the control circuitry is emphasized in (a), and the high voltage spark gap in (b). The entire unit is contained in an alodined aluminum enclosure measuring 18" W x 20" D x 7" high; there is an access door to change trigger voltage on the TM-11 trigger module. The unit, divided into two sections by an aluminum barrier, provides separate high voltage and control sections. The high voltage section contains the spark gap, two globar resistors, plus the trigger isolation capacitors and a one meg ohm resistor. The front portion contains a modular $\pm$15 VDC power supply, the TM-11 Trigger Module with the ceramic pulse transformer output terminals feeding through to the high voltage section, and the trigger, control and logic circuits mounted on 4" x 4" printed circuit boards. Also included is the VSWR trip circuit on a printed circuit board.

The crowbar for the high power visual amplifier stage uses an EG&G type GP12B vacuum arc. The crowbar design to protect the driver stage in the breadboard test uses the EG&G KN-2 Krytron, with an EG&G TR149 trigger transformer. The KN-2 is a cold cathode switch tube with a holding anode configuration which has had a particle emitter added to speed ionization. The power supplies involved each has a rapid overcurrent device which will work when the Krytron goes into conduction, thus turning off the high voltage supplies.

3.5.4 Testing

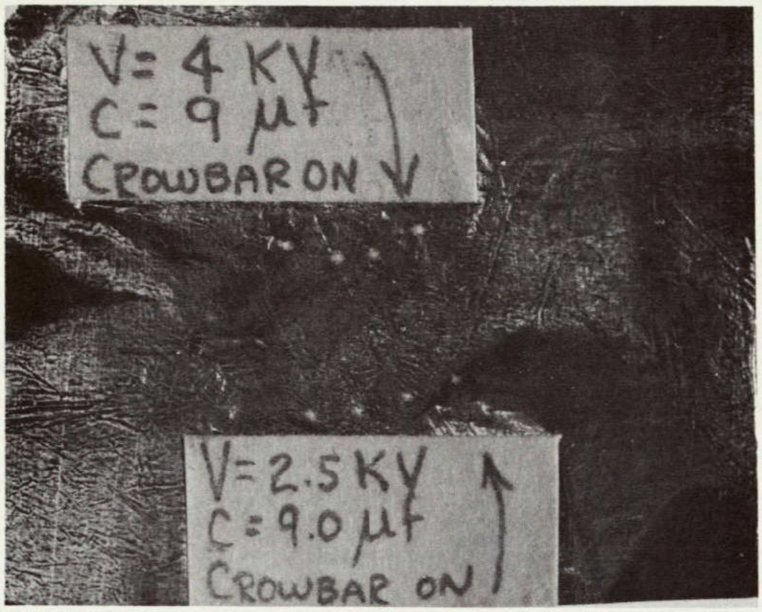
A vivid qualitative demonstration of crowbar circuit performance is the foil test. A piece of 0.5 mil (.0005") aluminum foil was placed at the high voltage potential. The power supply charged the 9 μf capacitor to 4 KV; the ground lead was then brough into close proximity and an arc started. The results, shown in Figure 3-18a, shows only an arc track left on the foil; the same test produced holes of approximately 1/8" diameter when performed without the benefit of crowbar protection, as in 3-18b.

(a) Control Circuitry

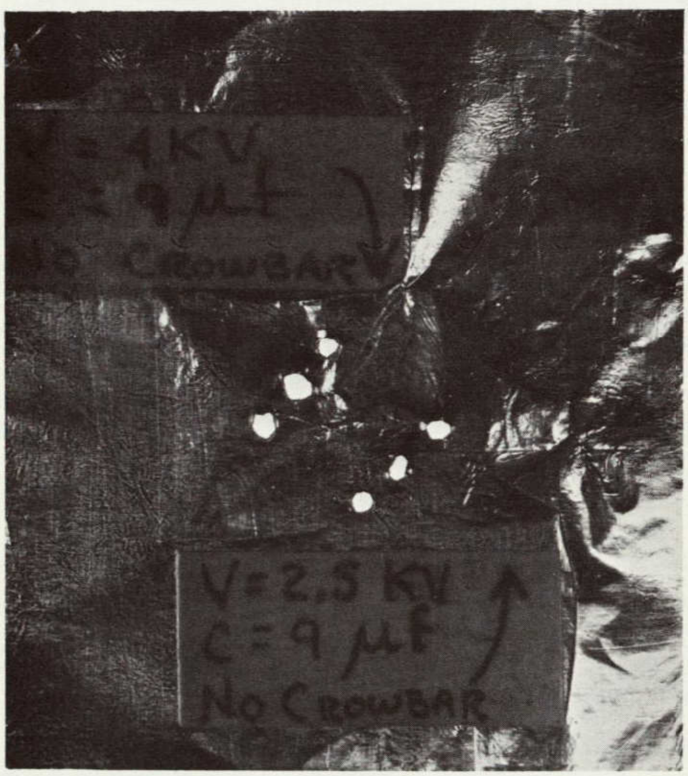


(b) Spark Gap Circuitry

FIGURE 3-17. CROWBAR AND SUPPLEMENTARY CIRCUITRY



a) With Crowbar



b) Without Crowbar

FIGURE 3-18. RESULTS OF CROWBAR TESTS

The driver stage crowbar was fabricated, installed in the power supply and tested using the foil test. With the voltage set at 1.0 KV, the nominal supply voltage, no visible damage to the foil resulted, indicating that the crowbar is sufficiently fast to offer full protection of the driver stage.

Thus, with a design tailored to closely fit the application, a high speed protection system has been realized which will ensure protection for the high powered spacecraft transmitter under many breakdown conditions.

Some difficulty was encountered in obtaining consistent firing of the large GP12BV spark gap during the testing at 4 KV (72 joules), which was due to the spark gap test energy level being well below the gap's rating. If an EG&G GP20A with an operating range of 1 KV to over 10 KV and a 200 joule gap were used, it would be smaller, require less trigger pulse amplitude (10 KV), and could be fired from medium power transistor stages working into a pulse transformer instead of requiring a separate trigger module. The use of a gap closer in size and rating to that required (150 joules) would probably give more consistent results and possibly simplify the resulting circuitry.

3.5.5 Monitor Circuitry

Requirements for control and protection of grounded grid triode rf amplifiers are reflected in the following sequence for turn-off of the transmitter.

Emergency Shutdown

1. VSWR Trip shuts off RF drive(and also HV if desired) when RF reverse power exceeds a pre-determined level.

2. The following Faults should turn off HV and RF Drive

   Plate Current Overload
   Grid Current Overload
   Crowbar Firing

Crowbar

The HV power supply should be crowbarred when excessive tube current is sensed. An auxiliary crowbar interlock closure is required to insure that the HV power supply is turned OFF.

In the Doherty circuit the control logic should actuate if either peak or carrier tube fault occurs. Monitoring of the following quantities is desired:

Doherty Visual Amplifier

- Carrier Tube Plate Current
- Peak Tube Plate Current
- Plate Voltage (common to both tubes)
- Carrier Tube Grid Current
- Peak Tube Grid Current
- RF Monitor Points
  - Carrier Plate RF Voltage Sample
  - Peak Plate RF Voltage Sample
  - Carrier Cathode RF Voltage Sample
  - Peak Cathode RF Voltage Sample
- Total RF Input Power (Forward and Reverse)
- Total RF Output Power (Forward and Reverse)

The circuitry to monitor these points, and the anode supply crowbar are in Figure 3-19.

Visual Driver

- Plate Current
- Plate Voltage
- Grid Current
- RF Output Power (same sensor as Doherty input is suitable)
- RF Input Power (Forward and Reverse)

Aural Amplifier - Same as Visual Driver

The monitoring and protective requirements for the driver and visual amplifier shown in Figure 3-20 indicate the location and relationships of circuit components in a simplified circuit diagram.

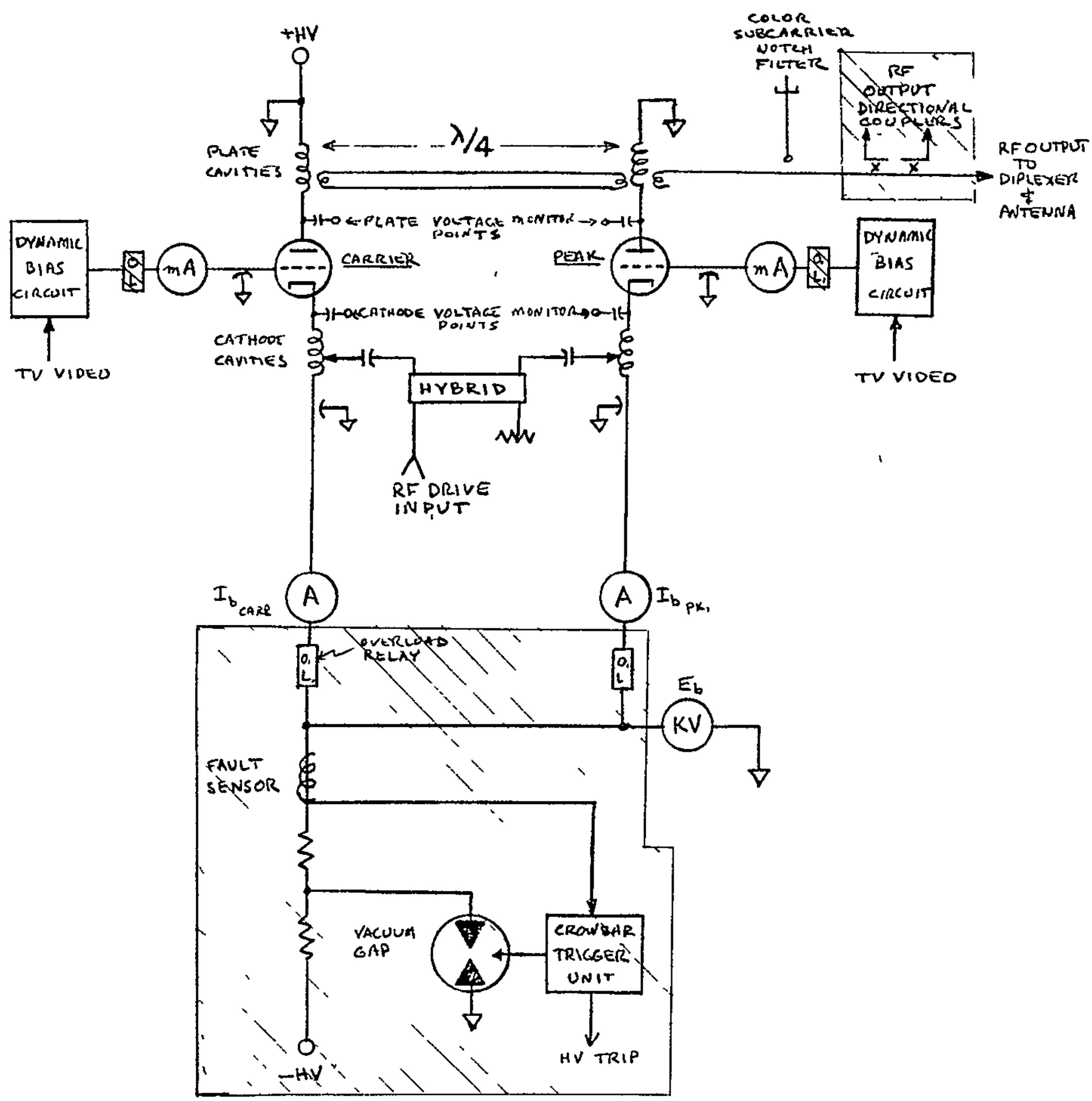


FIGURE 3-19. DOHERTY MONITORING AND PROTECTIVE CIRCUIT

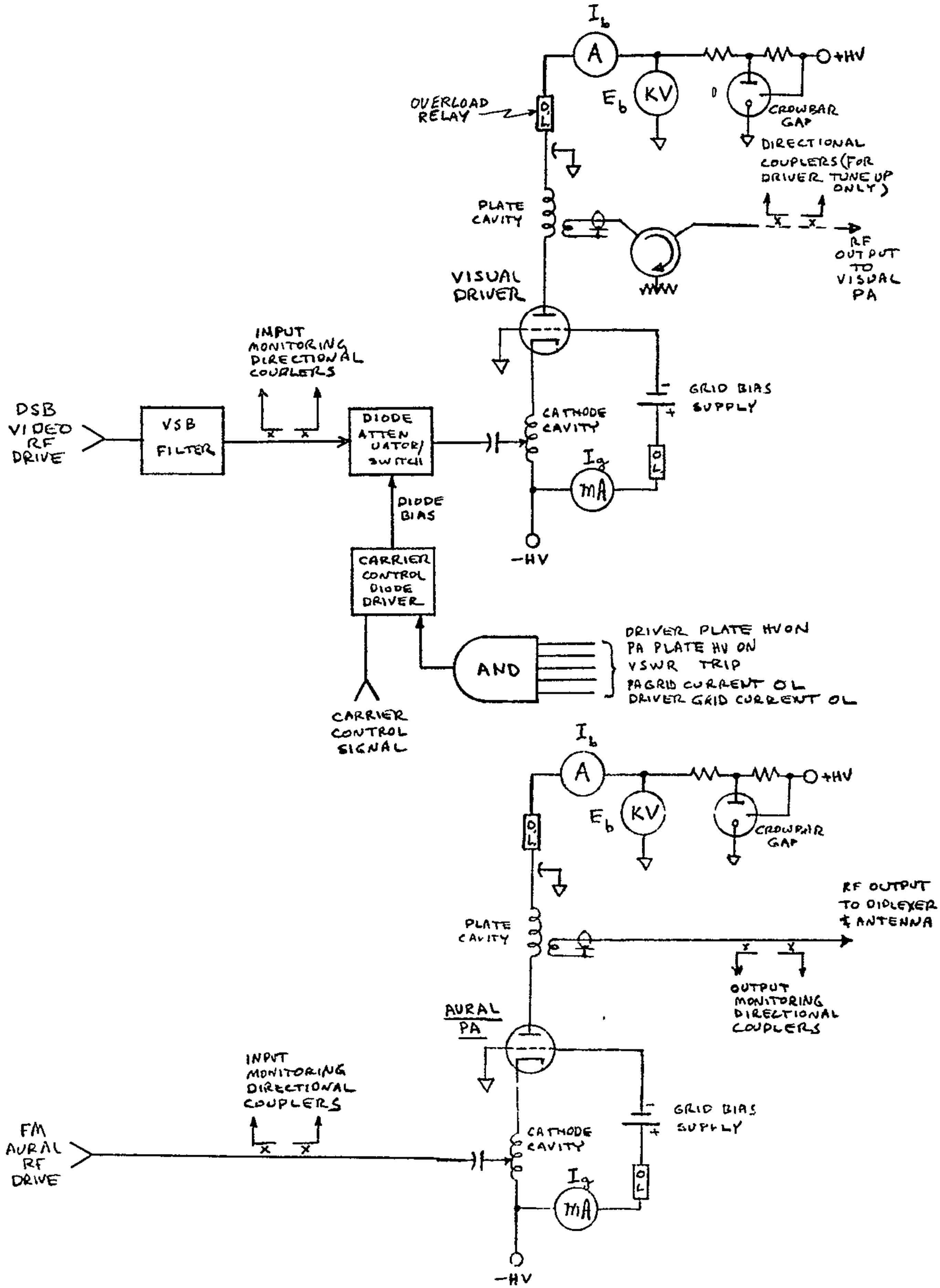


FIGURE 3-20. AURAL AND DRIVER MONITORING AND PROTECTIVE CIRCUITS

3.6 CONTROLLED CARRIER CIRCUIT DESIGN - TASK 6

3.6.1 Approach

This task was to design a "controlled carrier" modulator, or attenuator, for use with the 5 kW AM-TV transmitter breadboard. This circuit will permit the power supply and conditioner to be sized to the "average" transmitter power required for the TV signal. Carrier (or envelope) reduction for dark pictures has the effect of reducing the effective S/N by 1 or 2 dB, but this would normally not be noticed by the viewer. However, the technique can reduce power supply and conditioner capacity requirements by as much as 40%, which is highly significant to the satellite and system.

The approach employed in this task was to develop a suitable circuit design from the functional block diagram of Figure 3-21, using the performance specifications of Section 2.3.6 and 5.6 as a design guide. The resulting circuit is arranged to permit ease of parameter changes during development testing. Parts selection will be included in the task in order to facilitate purchasing and fabrication in the next study phase.

3.6.2 Circuit Design

The circuit design is based on the stages shown in the block diagram, Figure 3-21, and includes the functions of the four blocks in the left half of that figure. The final schematic diagram is shown in Figure 3-22, and comprises the power sampling circuit (including a 2 ohm resistor, R1, in series with the B-minus line), a threshold control in conjunction with the time-constant control circuit, the differential amplifier (using IC-1), and the RF drive attenuator with its attendant attenuator control circuit. A detailed description of circuit performance is given in Section 5.6.

The circuit is designed to vary the signal level of the driver input, and is included in the transmitter system block diagram of Figure 2-2. It can vary the RF signal level by at least 6 dB, although this range is not required for most TV signals. The unknowns in signal pre-emphasis makes a safety margin desirable, however. Computed operation

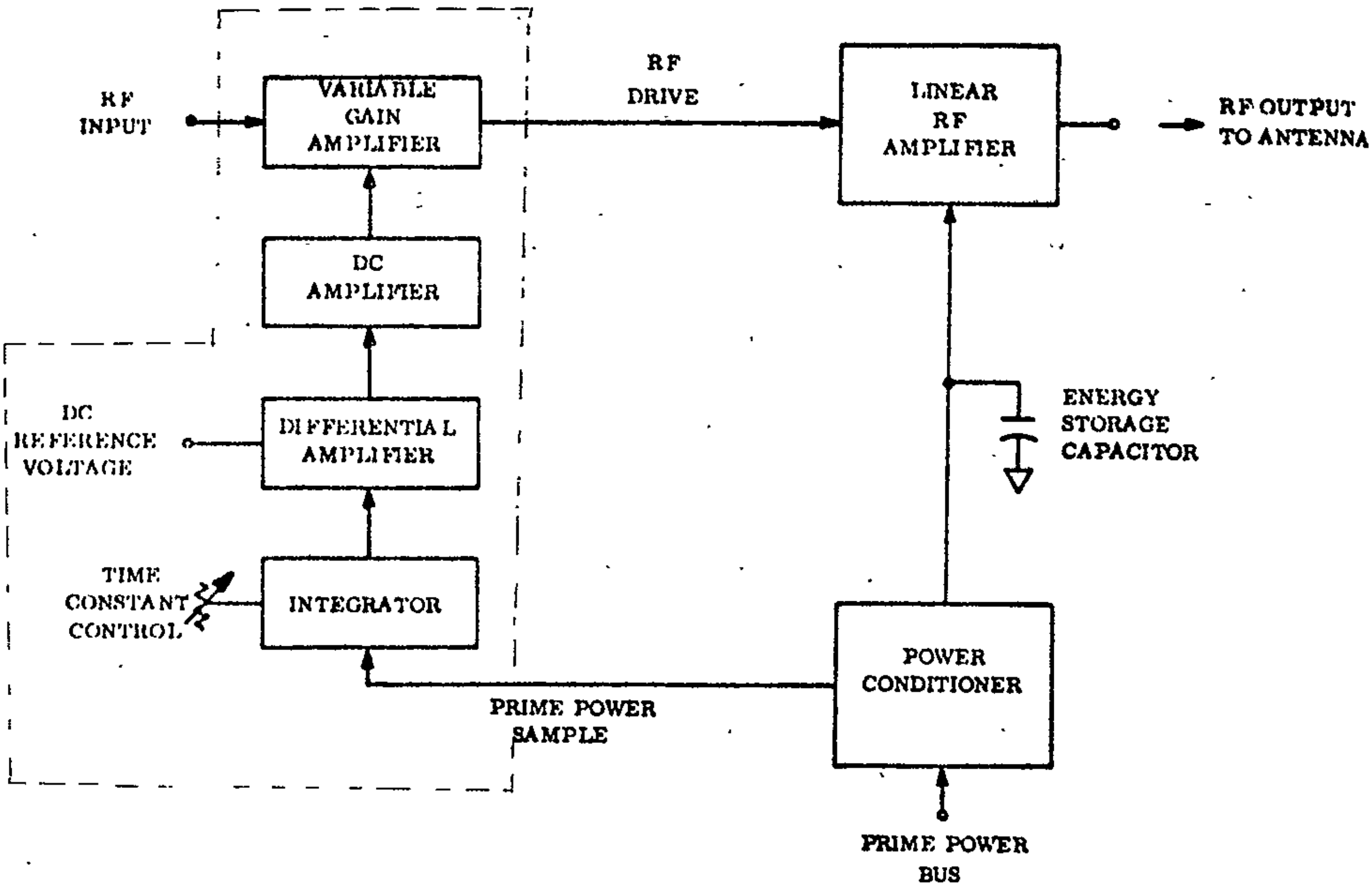


FIGURE 3-21. BLOCK DIAGRAM OF CONTROLLED CARRIER CIRCUIT

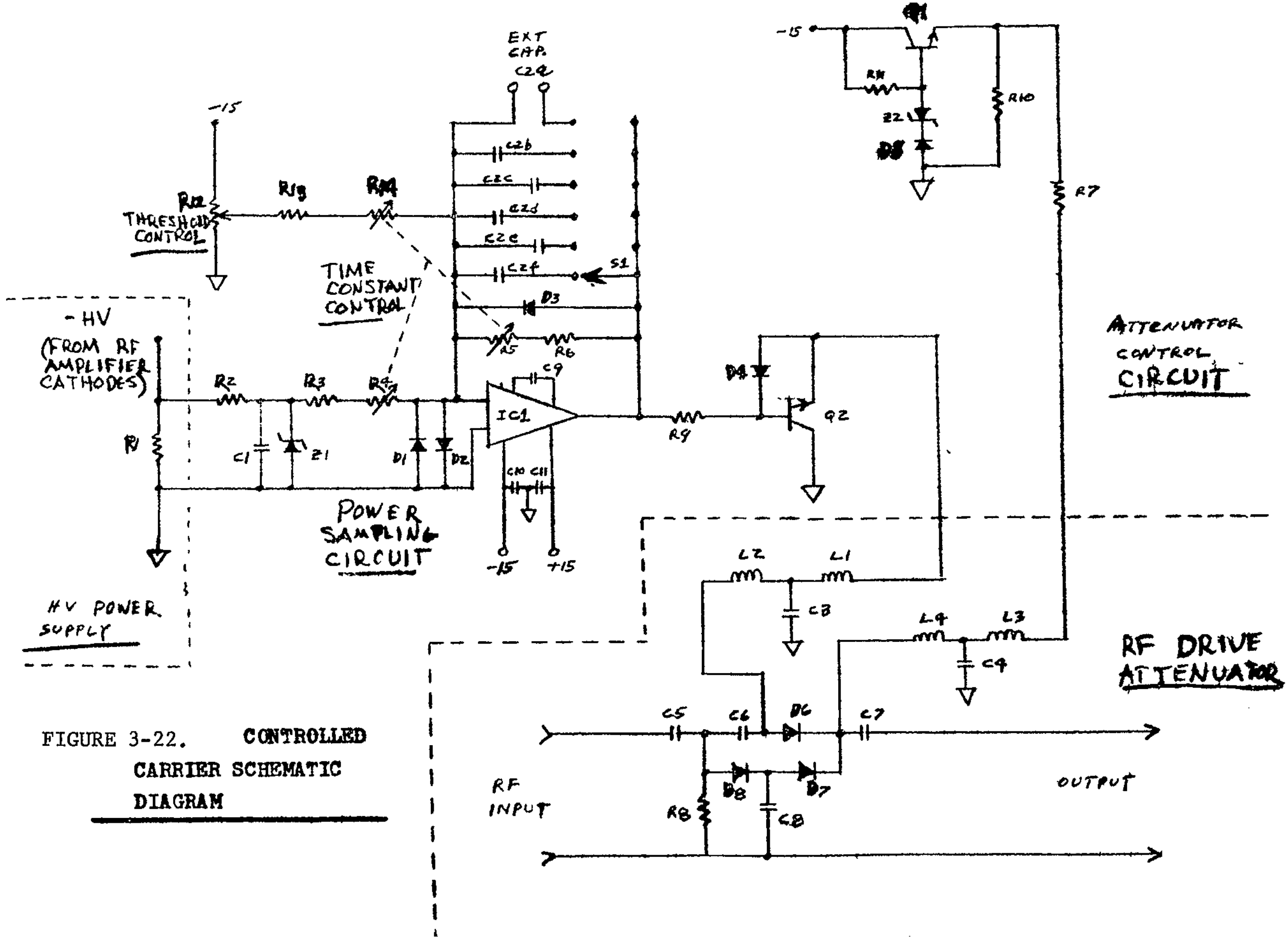


FIGURE 3-22. **CONTROLLED CARRIER SCHEMATIC DIAGRAM**

is:

Insertion loss = .282 dB

Range = 6 dB

3.6.3 Fabrication

The circuit should be fabricated using strip line techniques for the RF Drive Attenuator section. The Control Circuit should be fabricated on a base such as vectorboard. Testing should be a specific item in the overall test program for the transmitter.

3.7 HIGH POWER RF COMPONENT ENVIRONMENTAL TEST PLAN - TASK 7

3.7.1 Test Philosophy

A basic test program has been formulated for multipactor and ionization breakdown tests on selected components which are representative of those types likely to be used in a high power spacecraft transmitter. These tests will be performed at power levels up to 2.5 kW in a vacuum chamber; scaling of data will permit estimates of performance at higher power levels. High power operating and breakdown relationships have been considered extensively in a previous contract.(2)

The test plan, which is detailed in Section 5.7, describes objectives, components, techniques, test methods, and limits imposed in testing RF components for high power multipactor and ionizing breakdown under high vacuum conditions. The objectives of the tests will be to evaluate typical high-power test components in a simulated space environment, and also to evaluate means to avoiding breakdown through suppression and component configuration design techniques. Results of these experimental tests will provide vital experience and data on the occurrence and suppression of multipactor and ionization breakdown, including the identification of critical parameters for each component and of corrective measures required to suppress breakdown. Guidelines for the selection of future components are also expected to be derived from the results of these tests.

Multipactor breakdown has been discussed extensively in a previous contract [20,21] and is considered the most likely form of breakdown in a high power rf system which is operated in a vacuum environment. In this program task, therefore, emphasis is placed on multipactor breakdown, with incidental effort directed toward avoidance of ionizing breakdown in the test system. All results on breakdown of either type will be reported.

3.7.2 Test Parameters

The basic operating parameters for multipactor testing of the RF components are as follows:

1.	Frequency	700 to 900 MHz
2.	RF Power	2.5 kW CW or Peak
3.	Temperature	500^{o} F max.
4.	Pressure	Approx. 10^{-6} mm Hg

During Test experimentation, other relevant parameters to be measured include:

a) VSWR

b) Incident and Reflected Powers

c) Reflection Coefficient

d) Current (Multipactor Electron Density, if any)

e) Breakdown Voltage

f) Gap Spacing

g) fd product (MHz-cm)

h) Material (including surface treatment or other processing)

i) RF Pulse Shape

3.7.3 Test Components

The first test phase will be concerned with obtaining satisfactory operation of the vacuum test system with uniform coaxial line or waveguide used as the component under tests. Once this has been accomplished. a waveguide component and a coaxial component

with stepped gaps, shown in Figure 3-23 b and d, designed deliverately to multipact, will be independently inserted into the test circuit. These components will permit debugging and calibration of sensors for multipacting and other breakdown phenomena measurement. The test components can also be used in the evaluation of multipactor suppression methods.

Following tests on the stepped gap components, test of components with representative configurations will be performed; these components include:

- o Color subcarrier image notch filter
- o 3 dB sidewall coupler

The notch filter (folded) is shown in Figure 3-23a, and a 3 dB hybrid is in Figure 3-23c. Thus, a minimum of six components are anticipated to be tested:

- o standard WR975 half-height guide
- o 3-1/8" coax line
- o stepped waveguide section
- o stepped coax section
- o color subcarrier image notch filter
- o 3 dB sidewall coupler

In all of the tests, instrumentation for monitoring vacuum level, temperatures, multipactor action, and ionizing breakdown will be incorporated into the test set-up so that a comprehensive assessment of test circuit operation is obtained.

Items (b) and (d) in Figure 3-23 can be consideres as representative elements of reactive harmonic filters that might be used in a high power coaxial or waveguide transmission system, and are also representative of low impedance lines (coaxial, rectangular waveguide, and ridged waveguide) which are a possible approach to multipactor prevention. Both stepped units will be designed to accommodate variations in gap spacing, disassembly, inspection and cleaning. The stepped section components may also be used in the proposed test of flame sprayed materials which prior investigations have found to be

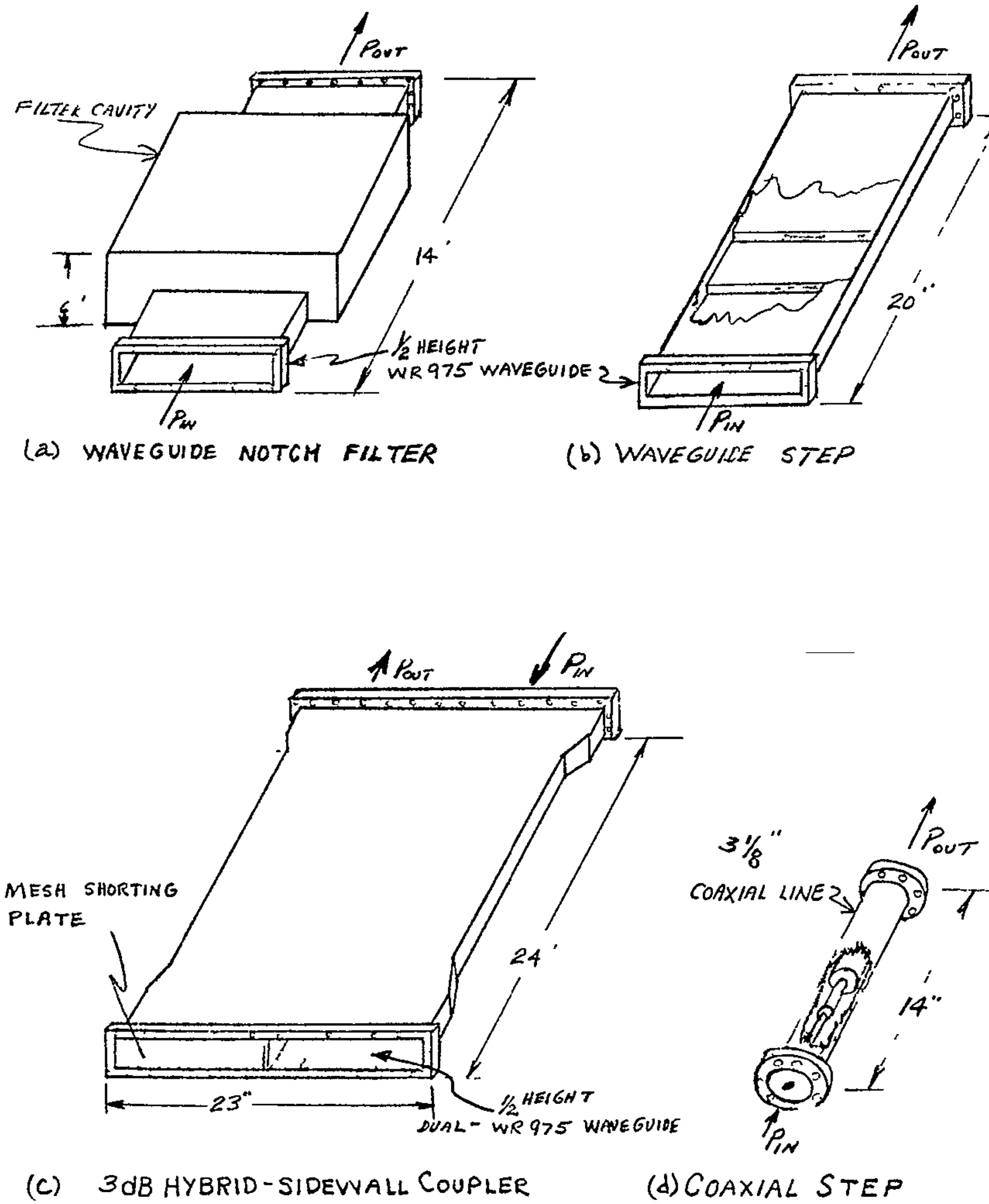


FIGURE 3-23. REPRESENTATIVE COMPONENTS SELECTED FOR MULTIPACTOR TESTS

useful in multipactor suppression.

3.7.4 Expected Results

From previous results[2], only multipactor breakdown is expected in the vacuum, and this should not appear in the standard waveguide, notch filter, or 3 dB hybrid up to the 5 kW level. The stepped sections may multipact. The power level where breakdown occurs would be compared with the theoretical level to ascertain validity of the analytic approach. The 3-1/8" coaxial line may multipact, but is a somewhat borderline case. The results of the tests will be a series of recommendations, including the design of non-multipacting components and the application of anti-multipacting techniques on multipactor-prone components.

3.8 TRANSMITTER TEST PLAN - TASK 8

3.8.1 Test Requirements

The transmitter test plan is designed to provide direction for obtaining performance data on the transmitter, including the measure its capability for performing as a TV transmitter. For space operation, the Controlled Carrier feature (Section 3.6) is deemed necessary, and the circuit will be tested further as a TV transmitter with that circuit in place. The specific parameters and performance characteristics included in the test plan are shown in Table 3-1; the list includes the fundamental operating measurements, fundamental TV measurements, and the various specialized tests and refinements to the test program, including controlled carrier operation. Separate aural channel measurements are also indicated in the table. An outline of the required test equipment is in Appendix B and the manner of measuring each of the items in Table 3-1 are presented in Section 5.8.

TABLE 3-1

MULTIKILOWATT TRANSMITTER PERFORMANCE TESTS

1. Efficiency as a function of RF drive level and TV picture content

   (a) Operating voltages and currents
   (b) RF power outputs
   (c) Power dissipation factors
   (d) Power gains

2. TV picture quality factors

   (a) Frequency response
   (b) Linearity (low frequency)
   (c) Differential gain
   (d) Differential phase
   (e) Envelope delay
   (f) Hum and noise

3. Harmonic and spurious outputs

4. Controlled carrier operation

5. Power supply regulation and effects of transient loading (i.e., during vertical sync interval) with and without controlled carrier operation

6. Upper and lower sideband attenuation in visual RF channel with VSB and color image filters

7. Aural channel modulation performance

   (a) Operating parameters
   (b) Transmitter bandwidth
   (c) Transmitter contributed AM

The test procedures follow the EIA suggested methods whenever applicable. Simultaneous operation capability of aural and visual channels is used where appropriate in these tests.

The basic exciter unit, assembled from items 3 and 12 through 17 in Appendix B, is shown in Figure 3-24. The exciter unit is designed to provide all the signals necessary for TV performance tests as well as the other parameter testing.

3.8.2 Test Purposes

A brief description of the purpose of each of the tests provides a basis for describing the overall breadboard transmitter test plan, outlined in Section 5.8 and Reference 18. The first group of tests in Table 3-1 is concerned primarily with the visual channel of the transmitter.

3.8.2-1 Efficiency Tests

The first set of tests measures transmitter operating parameters as a function of TV picture content. These tests are designed to provide a measured baseline of operating parameters (without the controlled carrier function in operation), including the measurement of heat dissipation of each portion of the transmitter.

3.8.2-2 TV Picture Quality

The frequency response test in group 2 of table 3-1 is intended to establish the overall video amplitude versus frequency response of the transmitter and to verify that the results are in accordance with the EIA standards. The low frequency linearity test is used to establish the output amplitude versus input amplitude relations for the transmitter. This test will also verify the compliance of the transmitter with paragraph B-9 of EIA Standard RS-240 (or equivalent) for visual broadcast equipment. The differential gain test is to measure the differential gain of a 3.58 MHz signal (color subcarrier) as the average picture level (APL) is varied from 10% to 50% and then to 90%,

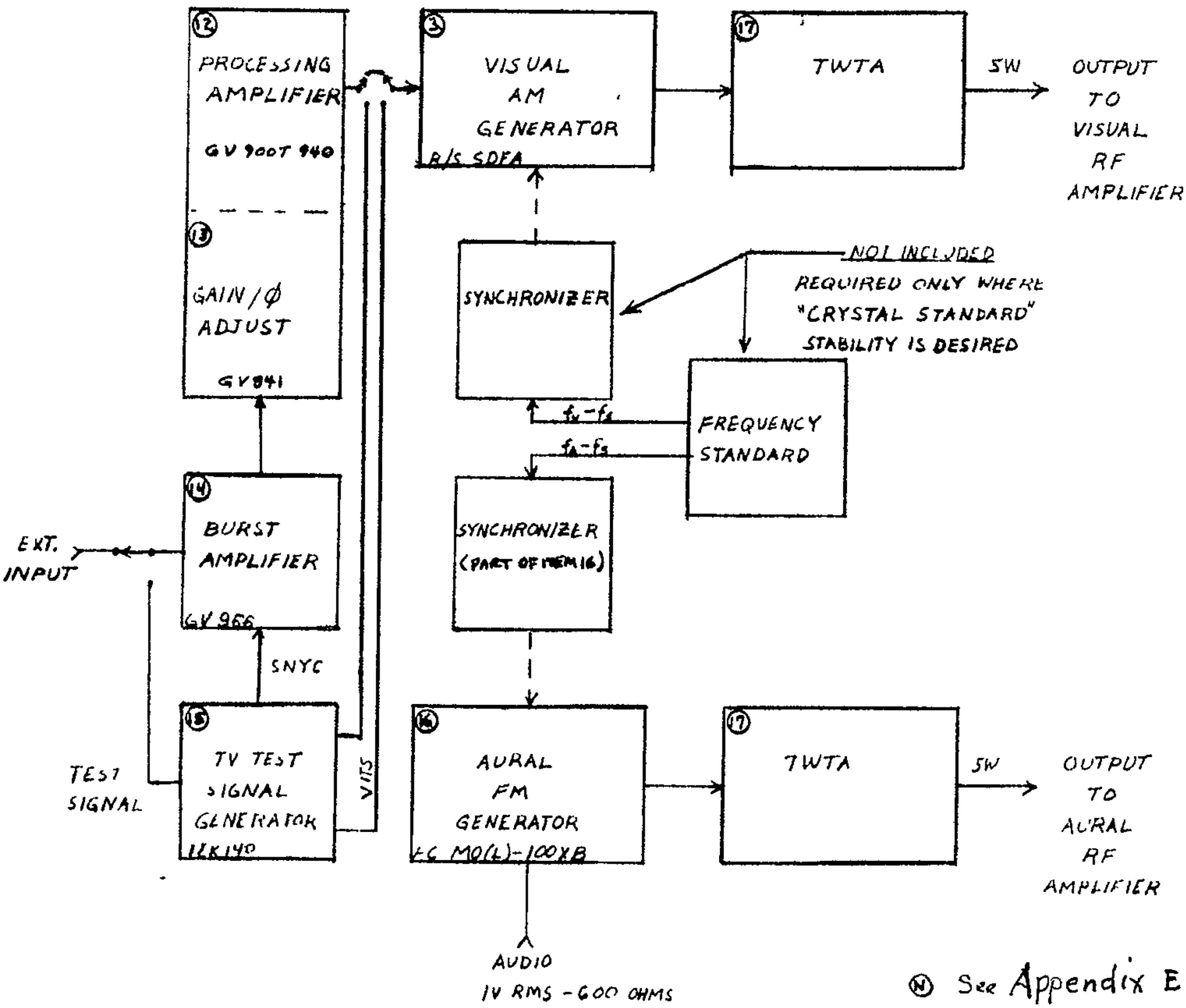


FIGURE 3-24. TEST EXCITER BLOCK DIAGRAM

while the differential phase test measures the differential phase of the signal under the same varying picture levels (paragraphs B-11 & B-10 of RS-240). Envelope (or group) delay versus frequency for the visual channel of the transmitter and hum and noise tests will also be performed in accordance with the EIA Standard.

3.8.2-3 Harmonics

The harmonic output test is designed to measure all harmonic, subharmonic and spurious radiations from the transmitter as an indication of the degree of filtering required in future transmitters of similar design in order to insure that these radiations are at least 60 dB down from the peak visual carrier power level.

3.8.2-4 Controlled Carrier Tests

The controlled carrier tests will permit evaluation of the controlled carrier mode of transmitter operation. The measurements taken for these tests will be compared with those taken for the transmitter in the normal mode of operation, and judgements will be made as to the relative effectiveness of the controlled carrier mode.

3.8.2-5 Other Tests

The power supply regulation test is designed to evaluate the performance of the power conditioner unit and LC filter when subjected to normal transient conditions. These transient conditions might be caused by radical changes in the picture content of the visual carrier. This test will be performed with and without the transmitter in the controlled carrier mode, and will enable the evaluation of additional possible benefits of the controlled carrier mode. The upper and lower sideband attenuation test measures the rf response in the sidebands of the visual rf channel with vestigial sidebands and color image filters being employed.

3.8.2-6 Aural channel tests

The last group of tests is concerned primarily with the aural channel of the transmitter. The operating parameter test measures the input power requirements, rf output power, and quantity and mode of heat dissipation for this section of the transmitter. Efficiency can then be computed from these measurements. The test will also aid in the design of ancillary equipment for spacecraft application. The aural channel bandwidth test is designed to measure the bandwidth characteristics (such as passband flatness) for this channel, and to indicate any possible degradation of the audio signal introduced by the transmitted aural channel amplifier. The final test measures hum and noise modulation present in the aural channel rf output signal amplitude which is contributed by the transmitter.

SECTION 4

RECOMMENDATIONS

This Interim Report is a progress report, and generally is intended to be just informative. However, the salient points for each task are included as a series of tentative recommendations, based on accomplishments to date.

4.1 TASK RECOMMENDATIONS

4.1.1 Transmitter System Design - Task 1

- Base transmitter electrical performance on a TV standard; EIA RS-240 will be used here.
- Use half height WR975 waveguide for transmission line and RF components. Coaxial line is more susceptible to electrical and thermal problems.
- The Vestigial Sideband Filter should be a low power type and used in an input circuit, in this program, it will precede the driver stage.
- The Y-1948 tube (production L-64S) is recommended for the high power stages for high efficiency at high power, the driver would use an ML-8534.
- The breadboard amplifier will be developed for channel 73, 825.25 MHz.
- Monitor and protective circuitry should include crowbars for dc protection and suitable RF sensors to detect RF breakdowns, an RF control circuit would prevent the latter from possibly disrupting the system.
- A controlled carrier circuit is necessary for a space AM-TV transmitter where conserving dc power is vital to achieve high efficiency.

4.1.2 Visual Channel Amplifiers - Task 2

Driver Stage·

- The grounded grid stage with double-tuned output circuit is adequate to drive the Doherty amplifier. The ML-8534 provides some power margin over requirements. Additional work is required to optimize the amplifier.

Doherty Output Stage:

- The Y-1498 will provide the required output with a high efficiency at the upper UHF TV bands.
- The cavity designs for the aural channel amplifier (Section 3.3 and 5.3) is suitable for the two stages of the Doherty amplifier.
- The likely form of input circuit will be a 3-dB hybrid which provides both the required power split and the -90° shift required between stages.
- Dynamic bias circuits will be included in both stages to obtain good linearity and a high efficiency.
- Fabrication will begin shortly, following evaluation of the aural channel amplifier operation.

4.1.3 Aural Channel Amplifier - Task 3

- If the grounded anode configuration continues to encounter problems with the grid by-pass capacitor, the circuit should be modified to a dc grounded grid rather than a dc grounded anode.
- The anode breakdown problem from multipacting should be considered for a space design.
- Thermal control for a grounded grid circuit presents additional difficulties which should be analyzed from a system viewpoint.
- Initial testing to be performed with loop coupling, iris coupling used in final tests.

4.1.4 RF Components - Task 4

High Power Components:

- The components developed meet or exceed specifications, an additional tuning means was necessary to obtain the 1.1 VSWR desired for the assembly.
- A 3 dB hybrid will be used for testing, but it is not required for general tests since it does not constitute a complete diplexer, individual loads on the aural and visual channels would be sufficient for performance testing.

Vestigial Sideband Filter.

- The low power filter fabricated for the test transmitter is theoretically adequate. Final transmitter tests will be required to assess the effects of non-linearities in the high power stages.
- The Q's of the reactive terminations were not adequate for the system requirements, these must be examined to determine whether the stripline or the dielectric is the primary cause of the discrepancy.

4.1.5 Monitor and Protective Circuitry - Task 5

- Circuitry developed for protection against dc arcing and high reflected rf power levels will turn off equipment to eliminate destructive effects of the breakdowns. The equipment developed will be incorporated into the final transmitter system.

4.1.6 Controlled Carrier Circuit Design - Task 6

- A circuit suitable for the controlled carrier function was designed; fabrication should be implemented at an early time to assure adequacy in the experimental version.

- Using a threshold circuit for actuating the controlled carrier circuit, a compromise on amplifier efficiency and power supply size can be effected. This compromise should be evaluated, but appears to be best with threshold set at the overall average power level.

4.1.7 High Power RF Component Environmental Test Plan - Task 7

- High power tests on rf components in a vacuum environment will pave the way for designing space qualified transmitter systems which will not be prone to rf electrical breakdowns.
- The program anticipated for this contract will cover components applicable to a UHF TV transmitter system, results can be extrapolated to estimate operation at other frequencies.
- Test techniques generally will be applicable to other components and other frequencies.

4.1.8 Transmitter Test Plan - Task 8

- The test plan provides a detailed direction of effort to evaluate the transmitter performance, both as a high power transmitter and as a TV transmitter. The plan should be implemented as soon as the Doherty amplifier has been tested, all other subsystems should have been completed and installed by that time.

4.2 CONTINUATION PLAN

The continuation of the program will include required additional circuit developments and the two test programs in order to achieve the objectives set forth in Sections 1.3 and 2.1 of this report. The specific tasks and the general direction of each are as follows:

- Transmitter System Design - Task 1

  Completed. No additional work to be performed.

- Visual Channel Driver - Task 2a

    Modification of output coupling loop, final test, complete 1 April.

- Visual Channel Doherty Amplifier - Task 2b

    Fabricate, starting in early March. Complete unit and test by 1 May.

- Aural Power Amplifier - Task 3

    Modify grid by-pass, final test. Complete by 1 April.

- RF Components - Task 4

    High power components completed.

    VSB Filter to be modified to improve skirt slopes. Complete by 1 April.

- Monitor and Protective Circuitry - Task 5

    Completed.

- Controlled Carrier Circuit - Task 6

    Fabricate and bench test by 1 June.

- High Power RF Component Environment Tests - Task 7

    Modify facilities as required, test rf source, fabricate components to be tested (where not already available).

    Perform high power vacuum environment tests, evaluate; complete by 1 June.

- High Power Transmitter Tests - Task 8

    Assemble transmitter system per Figure 2-2. Complete 1 May '70

    Perform the tests outlined in Test Plan. Complete 1 July '70

- Final Report

    Complete 1 August 1970

SECTION 5

DETAILED TECHNICAL RESULTS

These results are the detailed considerations of the results included in Section 3. In some cases where the task is still in process and data is incomplete, this section will not go into great detail. Task reports to be issued will expand on each of these areas. Where task reports have been prepared and data is complete for the moment, the essential details are included.

5.1 TRANSMITTER SYSTEM DESIGN - TASK 1

Much of this task represents the inputs, constraints, and specifications for the various other tasks. In general, only the unique results are included in this task, and those items relating to other tasks will be included in those appropriate sections.

5 1.1 Overall Requirements

The overall requirements for the breadboard transmitter were included in Sections 2.2 and 2.3. Since these are specifications and generally do not involve analysis from a system viewpoint, the details will be discernable in each of the task discussions. Some additional system implications are anticipated for inclusion in the final report, indicating the effects that the transmitter may have on a satellite system.

5.1.2 RF Components and Transmission Lines

In determining a preferred type of RF component and transmission line, considerations included 3-1/8" coaxial line, half height WR975 waveguide, and possible ridged waveguides. The latter would save on weight and size, but they tend to be very low in impedance. Thus, the impedance matching sections required as well as the higher losses would make this approach considerably more costly, and ridged guide appears to give little or no system improvement, especially in filters which might become quite lossy. It was not deemed practical to use the ridged guide for this program, and the standard guides were selected for the breadboard circuit Evaluation of low impedance line sections for vacuum breakdown susceptibility is, however, tentatively

planned for the Task 7 test program. (See Sections 3.7 and 5.7).

Results of earlier analysis (Reference 2) were scaled for operating conditions and the results are summarized in Table 5-1. On the bases of multipactor susceptibility, heating, and insertion loss, the waveguide components are generally superior to coaxial line. Waveguide is bulkier than coax, but is comparable in weight and may be lighter when the required thermal control measures are applied to the coaxial line inner conductor. Both coaxial line and waveguide reactive harmonic filters appear to be susce tible to multipacting. This can be circumvented by going to leaky wall absorptive designs (which are heavier and bulkier) or to closer spaced, low impedance versions Insertion loss for the waveguide circuit is expected to be about 1/2 that for a coaxial version. On the basis of the above considerations, the half-height WR975 waveguide component approach was chosen for the breadboard circuit

5.1.3 Tube Selection

A review of amplifier tubes for the three power amplifiers required in this transmitter was made. Comparisons were made on the basis of published or calculated efficiencies, calculated bandwidth, gain, circuit implementation factors, and cooling system requirements.

Efficiency was obtained, where available, from manufacturers data sheets or other published test results. In some cases estimates were obtained from calculations based on constant-current curve data for that tube, using the Fourier analysis method publishe by Eimac division of Varian[4].

Single tuned 3dB bandwidth was estimated from the "low frequency" method which is computed from the load impedance R_L and output capacitance C_o:

$$\Delta f = \frac{1}{2 \pi C_o R_L}$$

Bandwidth requirement is based on allowing 0.5 dB variation in response over a 5 MHz amplifier passband. Since the 0.5 dB bandwidth of a single tuned circuit is about

TABLE 5-1

COMPARISON OF RF COMPONENTS AT 5 KW

COMPONENT	OPERATING VOLTAGE KV	MULTIPACTING RANGE KV	HOT SPOT ΔT ^{o}C	COMMENTS
1/2 HEIGHT WR975	1.5	7.5 - 30.	0.5	
3-1/8" COAX	0.5	0.55 - 5.	10.	ONE STUB PER FOOT
WR975 HARMONIC FILTER	0.57	0.25 - 1.3	1.3	
COAX HARMONIC FILTER	0.5	0.18 - 2.4	75.	STUB AT ENDS (1 FT. LONG)
WR975 AURAL FILTER	3.4	7.5 - 25.	1.5	
COAX AURAL FILTER	8.4	13. - 30.	44.	
WR975 HYBRID	1.5	7.5 - 30	1.	ESTIMATED
COAX SLAB HYBRID	0.45	0.18 - 2.4	37.	STUBS AT CONNECTORS
COAX BRANCH HYBRID	0.41	0.4 - 3.0	20.	ESTIMATED; STUBS AT CONNECTORS

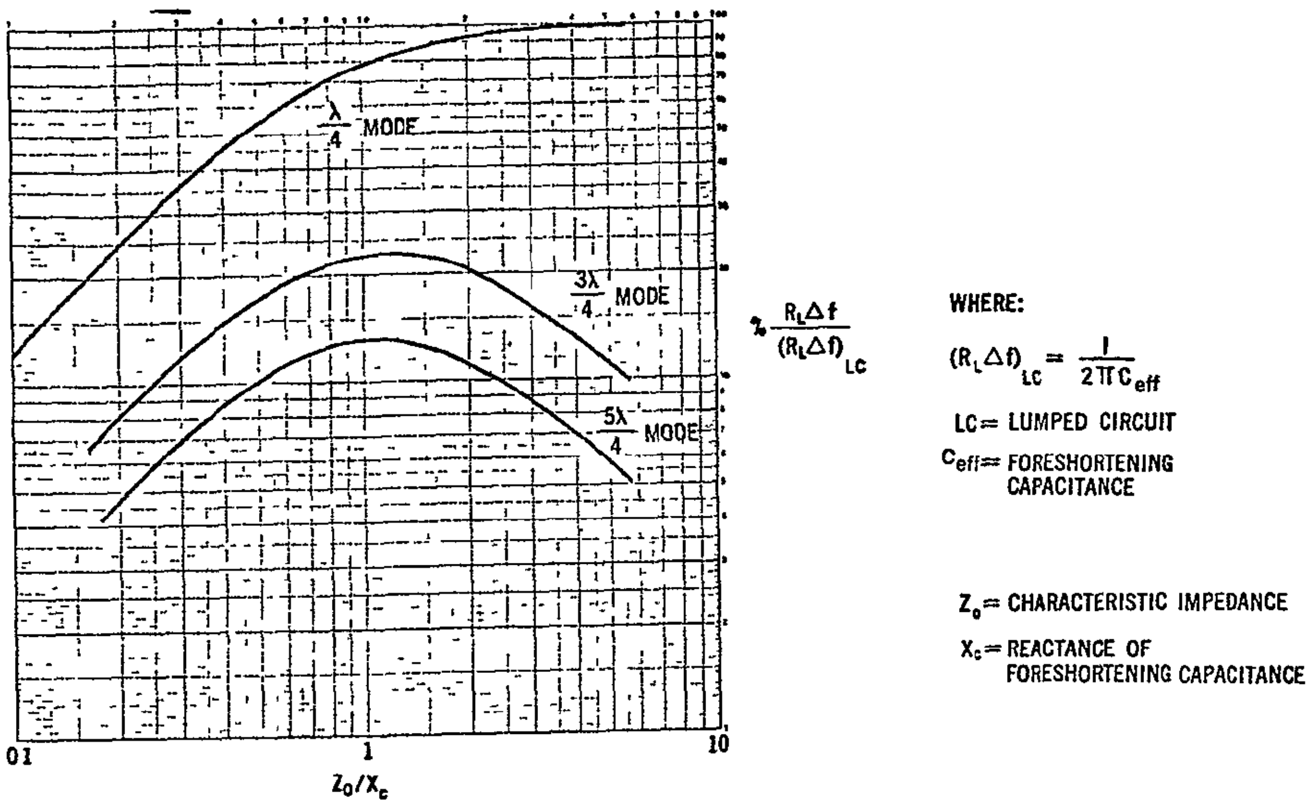
35% of the 3 dB bandwidth, Δf must be at least 14.3 MHz for the amplifier to be within EIA specifications. Generally, the output circuit of a grounded grid amplifier, rather than the input, is the constraining item in determining amplifier bandwidth Knowing the "low frequency" bandwidth, there are two additional factors to consider.

First, the bandwidth of a tank circuit utilizing transmission line elements is always less than the "low frequency" (i.e., lumped-element) circuit bandwidth. Bandwidth reduction factors are shown in Figure 5-1(a).(4) This figure illustrates the advantage of using resonators one-quarter wavelength in length. Larger tubes, requiring three-quarter wavelength resonators at operating frequencies in the upper UHF TV Broadcast Band, have only about 25% of the intrinsic bandwidth capability of the electronic structure of the tube due to parasitic impedance elements associated with the particular tube construction. Typically, quarter wavelength mode cavities will have bandwidths of about 70% of the "low frequency" bandwidth. Therefore, tubes with Δf of 20 MHz or more with $\lambda/4$ mode resonator capability, are of primary interst.

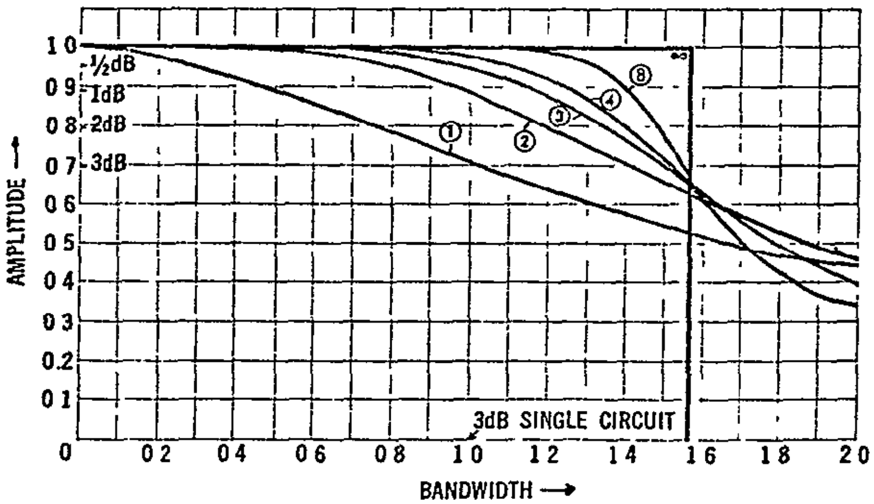
Secondly, additional 0.5 dB bandwidth capability is realizable if multiple tuning is used as illustrated in Figure 5-1(b). As an example the 0.5 dB bandwidth of a double tuned circuit is 2.14 times that of a single tuned circuit operating under the same tube operation conditions. Use of this arrangement would allow the use of tubes with smaller 3dB bandwidth capability, say around 10 MHz

In the above Δf Equation, R_L is set primarily by required power output and maximum tube ratings, while C_o is taken from the tube data sheet for this rough estimate. (In more precise calculations, the actual tube cross-section must be analyzed to correct C_o for tube parasitic element values.)

Over twenty tube types were considered or reconsidered in this review. The two chosen types are compared with " runner-up" choices in Table 5-2. The Y1498 (former designation was L-64S) is a clear choice for the Doherty visual amplifier application from



(a) Bandwidth Reduction Factors for Transmission Line Resonators



(b) Bandwidth Relations for Multiple Tuned Resonant Circuits

Figure 5-1. Bandwidth Relations for RF Amplifiers

Table 5-2

TUBE SELECTION

NUMBER	TYPE	MFGR.	P_o KW	CLASS B η - %	BW MHz	GAIN dB	COMMENTS
VIDEO P.A.							
L-64S (Y1498)	TRI.	GE	2.5	61	31	19	$\lambda/4$ INPUT AND OUTPUT
GL6942	TET.	GE	1.0	55	12	10	$\lambda/4$ OUTPUT CIRCUIT
7213	TET.	RCA	1.3	54	13	13	$3\lambda/4$ GRID AND PLATE LINES
VIDEO DRIVER							
ML-8534	TRI.	MACH.	0.32	51	31	15	CONDUCTION COOLED, $\lambda/4$ CIRCUITS
ML-8536	TRI.	MACH.	0.18	49	29	15	EXTERNALLY SAME AS ML-8534
8226	TET.	RCA	0.11	34	8	-	PLATE $\lambda/4$, CATHODE $3\lambda/4$
AURAL AMPLIFIER							
L-64S (Y1498)							

standpoints of power output, efficiency, gain, and bandwidth. The Y1498 is also adaptable to conduction cooling at high operating temperatures, a feature which is not offered by the other two listed tubes. The same tube is also a good selection for the aural amplifier.

At the 125 watt level, which is a conservative operating power margin for driving two Y1498 tubes with normal circuit losses, the Machlett ML-8534 is a preferred candidate. A similar tube, the ML8536, would be the choice for lower driving levels. Both tubes are conduction cooled and have good efficiency and bandwidth compared to competitive tubes. General Electric's developmental type Y1774, a potential candidate for this application, is in the same general class as the ML-8534 but has a higher operating temperature capability which is advantageous in thermal rejection from the spacecraft. Little data on the tube is available at this time and lack of assurance on its availability and consistency led to its rejection as a candidate for this program.

The experimental L-64S (Y1498) was designed for long life space applications, but there is a need to verify the life capability through a life test program. Limited data available on the ML-8534 indicates a life expectancy of greater than 5000 hours in applications roughly comparable to that in this transmitter.

5.1.4 Doherty Visual Channel Requirements

Performance requirements of the TV transmitter visual channel are outlined in detail in EIA Standard RS-240. In implementing this particular breadboard system, several performance factors are of particular interest in connection with implementation of the high efficiency amplifier

- Maximization of dc to RF conversion efficiency
- Acceptable gain and phase linearity over the TV signal dynamic range
- Acceptable frequency response characteristics

In the Doherty amplifier, approximately linear operation is obtained by judiciously

combining the outputs of two RF amplifiers, one of which is an inherently non-linear Class C amplifier. Also an examination of the circuit's operational characteristics reveals the possibility of bandwidth changes over the dynamic range of the TV signals. These factors plus the decisions on approaches and apportionment of performance factors and tolerance factors will be considered in this section.

Performance parameters of the transmitter breadboard are:

Peak sync Power - 5 kW

Visual channel (2 stages) gain - 30 dB

Operating Frequency - TV channel 73, 825.25 MHz

Response - nominally + 1.0 dB, -1.5 dB; 824.75 to 829.43 MHz

Out of band response (f_V is carrier frequency): See Figure 5-2(a); from f_V - 1.25 MHz to f_V - 4.25 MHz: 20 dB below f_V + 200 kHz response; at f_V - 3.58 MHz: 42 dB below f_V + 200 kHz response

Modulation Linearity (low frequency) - 1.5 dB maximum difference in gain at 10%, 50%, and 90% average picture levels (APL)

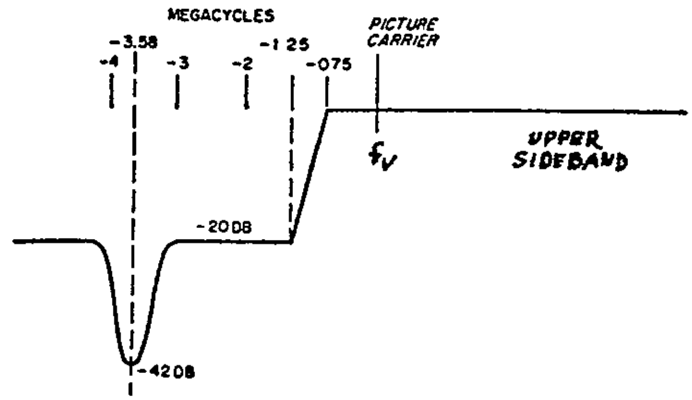
Differential Gain - 1.5 dB maximum difference in gain of a 3.58 MHz signal at 10%, 50%, and 90% APL

Differential Phase - Less than $\pm 7^\circ$ at 3.58 MHz referenced to the burst region for any video brightness level. In addition, the total differential phase between any two brightness levels shall not exceed 10°.

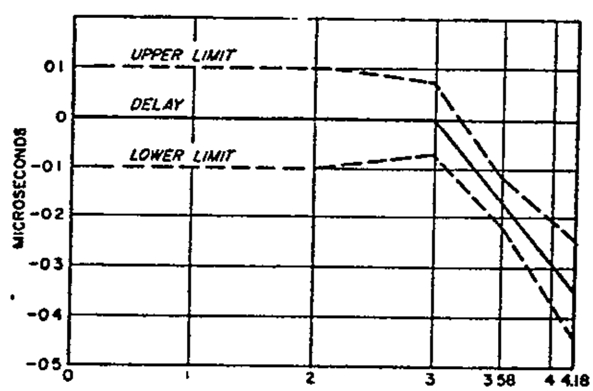
Envelope Delay - See Figure 5-2(b)
Nominal value at 3.58 MHz is -0.17 μsec which corresponds to 3.82 radians or 219°. The delay tolerance is $\pm$ 0.04 μsec at 3.58 MHz and increased to $\pm$ 0.09 μsec at 2.0 MHz and 4.18 MHz. An ideal VSB receiver is assumed in making the above video input to detected rf output video measurement.

These specification factors restrict the performance limits of subsystems in the visual signal transmission chain, and must be considered along with component and circuit capabilities in setting up the subsystem specifications. The allocations of performance parameters are discussed in the following paragraphs.

A simple block diagram of the visual signalchain with expected power levels and gains is shown in Figure 5-3. Bandwidth of the Y1498 is estimated to be about 55% of the lumped constant value of 19.2 MHz. This gives a response of about -0.5 dB at the edges



a) Vestigial Sideband Response



b) Envelope Delay

Figure 5-2. Visual Channel Specifications

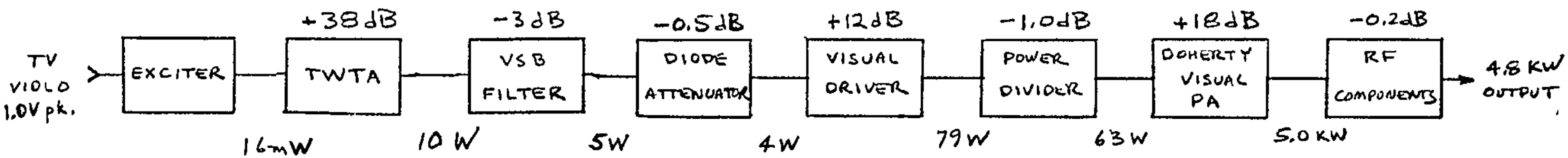


Figure 5-3. Visual Channel Signal Chain

of the video passband. The Driver Bandwidth is about 70% of the lumped constant value, or 21.7 MHz, which gives a response about -0.3 dB at the edges of the video band. Since these are the major bandwidth limiting factors in the amplifier chain, an adequate margin for exciter performance degradation exists and no problem with video response is expected under full output conditions.

Variation in bandwidth in the Doherty amplifier is expected to occur over the dynamic range of the TV signal since both of its amplifiers see varying impedances (though somewhat compensating) as drive level changes. This effect will be investigated in the Doherty amplifier design, but is not believed to be serious. A cursory examination of delay relations(7) indicates the differential phase due to the approximately 0.3 dB reduction in bandedge response at low signal levels is only about 1° at the color subcarrier frequency

Out-of-band response can be controlled by controlling bandpass at the output transmitter or by introducing selectivity in lower power level stages of the signal chain High selectivity (as indicated by the $<1\%$ bandwidth of the TV channel at UHF frequencies) comes at a high price in component size and power loss. The approach, therefore, was to place most of the selectivity in the low level stages. This approach, however, could result in excessive levels of intermodulation products generated in the amplifier stages if they are not sufficiently linear. Since high power linear amplifiers typically generate levels of -25 to -35 dB in two-tone intermodulation tests, it is reasonable to expect the color subcarrier image specification of -42 dB will be the only problem. This is rejected by using a simple notch filter in the transmitter output, as is common practice in modern transmitters.

Modulation linearity is a potential problem in any of the high power amplifier types. The Doherty amplifier has the usual linearity problem associated with gridded tube amplifiers plus the "switching" and load variations associated with activation of the

peak stage of the Doherty amplifier at levels above carrier level. Tests with the 30 MHz Doherty simulator indicate these effects are tolerable if a dynamic bias control is used to improve the linearity of the Doherty amplifier stages. Even with this, it is likely that some gain/phase linearity corrector may be required in the video driver to meet system performance requirements. This is normal practice in color television systems. Most non-linearities are expected in the high level stages where a tradeoff must be made between linearity and efficiency; an objective total 1.5 dB maximum allowable non-linearity is allocated to the Visual Drive plus Power Amplifier. Since their non-linearities are likely to be additive, a 1.0 dB tolerance in the Doherty and 0.5 dB in the Driver is probably a reasonable division.

Differential gain characteristics, which are measured at 3 58 MHz, should be close to the low frequency non-linear characteristics. However, factors such as the variable bandwidth characteristic in the Doherty amplifier may cause additional gain changes with signal level. Simiarly, differential phase characteristics are dependent on controlling variations in bandpass characteristics over the signal dynamic range With wide bandwidths, these variations are expected to be within acceptable limits. In any event, the differential gain/phase corrector mentioned earlier would be incorporated ultimately in the video drive circuit to allow trimming gain/phase variations of the system to an optimum value. Control of envelope delay within the required limits also is normally controlled in the video drive circuit to correct for characteristics of the particular transmitter. The degree of correction will be determined after the breadboard is in operation.

Gain and phase linearity in the transmitter-to-antenna chain may be adversely affected by multiple signal reflections from waveguide components or antenna impedance mismatches. In gridded tube transmitters these effects are of particular concern since the source VSWR of the transmitter is high, and re-reflections of any power reflected from the transmission line and its elements would have about the same amplitude as the reflected

signal. Thus, control of transmission components and antenna to result in a low VSWR is ncessary to avoid excessive gain and phase ripple in the passband. Short transmission lengths in the spacecraft would tend to reduce this problem. Thus, low VSWR specifications throughout the RF assembly are required.

5.1.5 Mechanical Design

A prime requirement for breadboard circuits is accessibility. Secondly, it should fairly represent the final circuit to avoid major alterations in design when carrying out succeeding stages of development. An approach which fulfills these requirements to a reasonable degree with consideration for personnel safety is proposed.

The rf components, ancillary circuits (usually based on semi-conductor active devices), and power tube anodes normally require separate heat sinks so that each can operate at the highest feasible temperature in consideration for minimization of thermal control system size and weight. (It should be feasible to mount rf components and ancillary circuits on a common heat sink.) The proposed breadboard layout uses heat sink plates, which simulate a spacecraft thermal control surface, for the rf components including amplifier cavities. The heat from the high power tube anodes is then conducted through openings in this plate to a second plate, which would be a heat pipe augmented heat sink on the spacecraft, operating at a much higher temperature than the rf component mounting plate. In the breadboard transmitter, water cooling connections for the tube anodes would be used, or the optional proposed heat pipe system now under development in a company funded program may be used in a demonstration of an integrated amplifier/heat pipe system.

The basic layout for this circuit has been shown previously in Figure 3-2. An aluminum plate, which will be cooled as necessary, will be used to mount the four amplifier cavities of the breadboard transmitter and the other rf components. For personnel safety or convenience, some components such as power supply crowbar, dynamic bias control circuitry, and protective circuit logic will be mounted in the laboratory

power supply rack. These components will be designed to be readily separable for delivery to the customer upon conclusion of the contract. The waveguide components have adequate surface area for self-cooling, and will simply be bolted in place against the waveguide outlets of the power amplifiers.

5.1.6 Crowbar Circuit

The function of the crowbar circuit is to divert current from the power supply and power supply energy storage elements from the high power tubes in the event of an internal tube arc, thus preventing excessive energy dissipation in the tube arc and subsequent damage to delicate tube components. A basic crowbar circuit is shown in Figure 5-4. In the event of a tube fault, a signal derived from the fault current sensing element activates the trigger unit, firing a crowbar element which places a low impedance across the power supply leads. Simultaneously, a "turn-off" signal is fed back to shut off the power supply. The energy dissipated in the tube is only a few joules; most of the energy stored in the power supply is dissipated in the crowbar arc. Two resistors are normally used in the circuit as shown. Resistor R-1 limits peak fault current to a safe value which precludes damage to the energy storage capacitor and the crowbar device. Resistor R-2 insures that the majority of the fault current will flow through the crowbar device rather than through the tube. The trigger unit normally contains a repetative firing feature, insuring that a significant charge cannot reappear in the energy storage capacitor in the event the crowbar device extinguishes before the power supply is turned off.

A survey of crowbar device types was made, and their relative merits are compared in Table 5-3. The vacuum spark gap was chosen for the high voltage power supply. The filter in this power supply contains a large energy storage capacitor, so the ruggedness of the vacuum gap must be sufficient for a long gap life. The relatively simpler Krytron* is a good choice for use in smaller power supplies.

* Trademark of EG&G

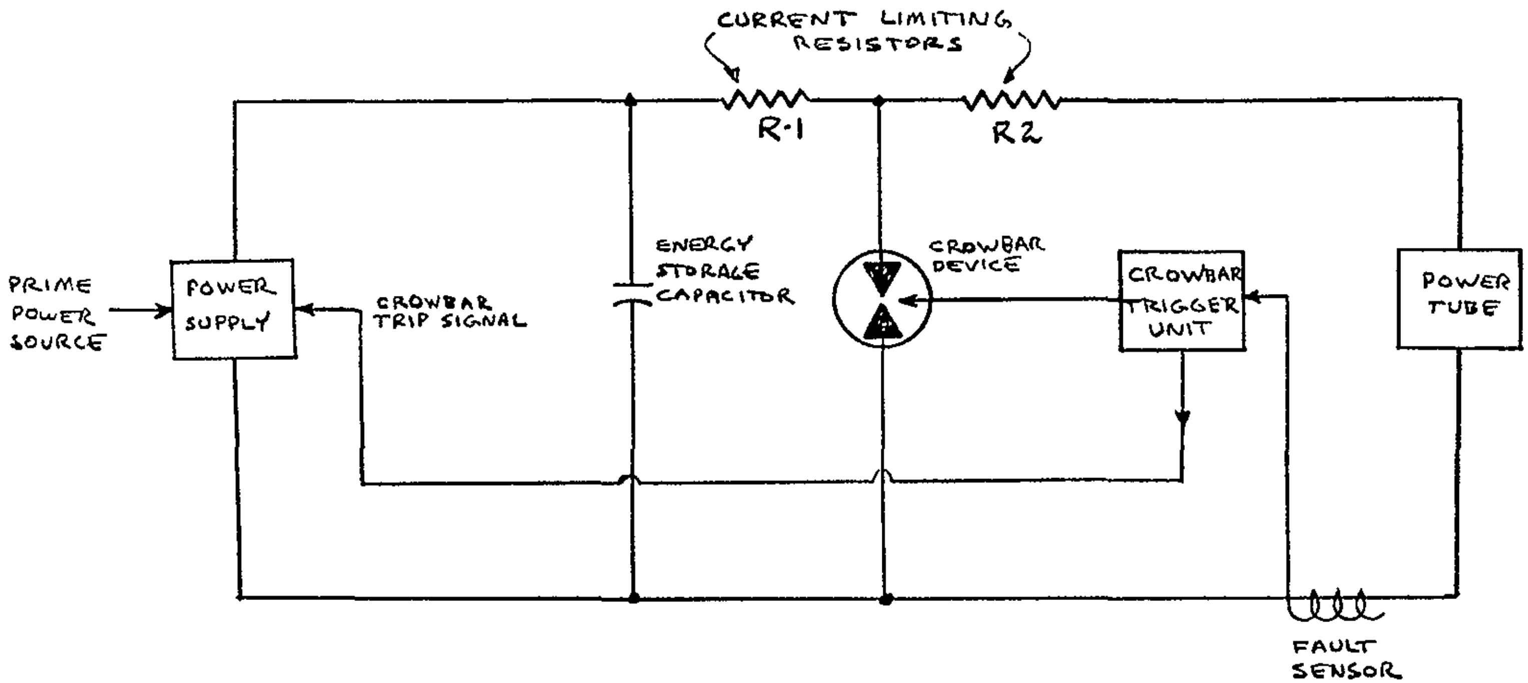


Figure 5-4. Basic Crowbar Circuit

Table 5-3. Crowbar Device Comparison

TYPE	TYPICAL EXAMPLE	ADVANTAGES	DISADVANTAGES
1) Spark Gap	Gas Filled Type	Can handle very large currents for longer times, simple rugged construction -- requires no keep alive current.	Possibility of leakage of ionizing gas.
	Vacuum Gap	Same as gas filled gap + wider operating voltage range than gas gap.	Erosion and sputtering cause failures, require currents on order of 1 amp to maintain conduction, therefore repetitive firing may be necessary.
2) Cold Cathode Switch Tubes	Krytron (EG&G)	Very small size and fairly large current handling capabilities. Very little delay (ns) and fast ionizing time (μ sec). Low voltage trigger, will conduct at current levels down to milliamperes.	Glass envelope construction, ionizing gas filled keep alive current. Generally low energy capability $\leq$50 joule life limited by cathode deterioration. Keep alive current contributes to gas clean up.
3) Hot Cathode Switch Tubes	Hydrogen Thyratron	Fast firing and ionizing (on order of 1 μsec)	Requires high amounts of heater power (up to 50 W) for larger versions, some are glass envelope (vacuum tube) types.
4) Solid State	Silicon Controlled Rectifier	Requires no heater/filament power, higher reliability by virtue of solid state properties (no vacuum seal or glass envelope)	Highest voltage rating presently available about 1700-2000 volts DC, slower turn on time depending on gate characteristics ($\geq$2 μsec). Higher voltage ranges require series connections of these devices with attendant reduction of reliability.

Available vacuum gap sizes fall on either side of the required value. The larger of the two sizes closest to the design value were chosen for reasonable gap life. A suitable type is the EG&G GP-22A. EG&G type KN-2 Krytrons* are suitable for aural amplifier and visual driver protection, which involve less energy storage than the Doherty Amp.

5.1.7 Controlled Carrier Subsystem

A company-funded development program(7) evaluated a proposed means of amplitude modulated television transmitter carrier control (a form of Automatic Level Control) as a means of more efficiently utilizing the spacecraft prime power source capability. The need for this feature arises from the fact that the average energy content of a U.S. Standard composite TV signal varies over a 4.8 dB range for a fixed sync peak power level, and the dc power required for a high efficiency amplifier follows the average RF power variation. Recent studies indicate that optimum dc power systems for space broadcasting will have no battery storage capability for the high power transmitter, so the prime power system must be sized for maximum average power requirement, which occurs with a black picture in the US and most other TV systems. The study indicated that the sync peak output level of a simulated high efficiency transmitter could be regulated so as to maintain prime power requirement constant at the average gray picture level (32% duty) with no discernible effect to the average viewer as long as the level controlling circuit has a time constant response the same as or somewhat longer than the receiver AGC circuit. It is then possible to size the power source for an average gray level power demand rather than for the maximum at black level video. The savings in prime power would typically be around 30% for the Doherty amplifier circuit.

A basic carrier control circuit modeled in the above mentioned program is shown in Figure 5-5. Basically, this circuit varies the RF drive signal amplitude such that the average power in the transmitted signal is constant. Thus, the sync peak power would be high for a white picture which requires relatively little picture power, and would be low for an all black picture which requires a high picture power. Variation

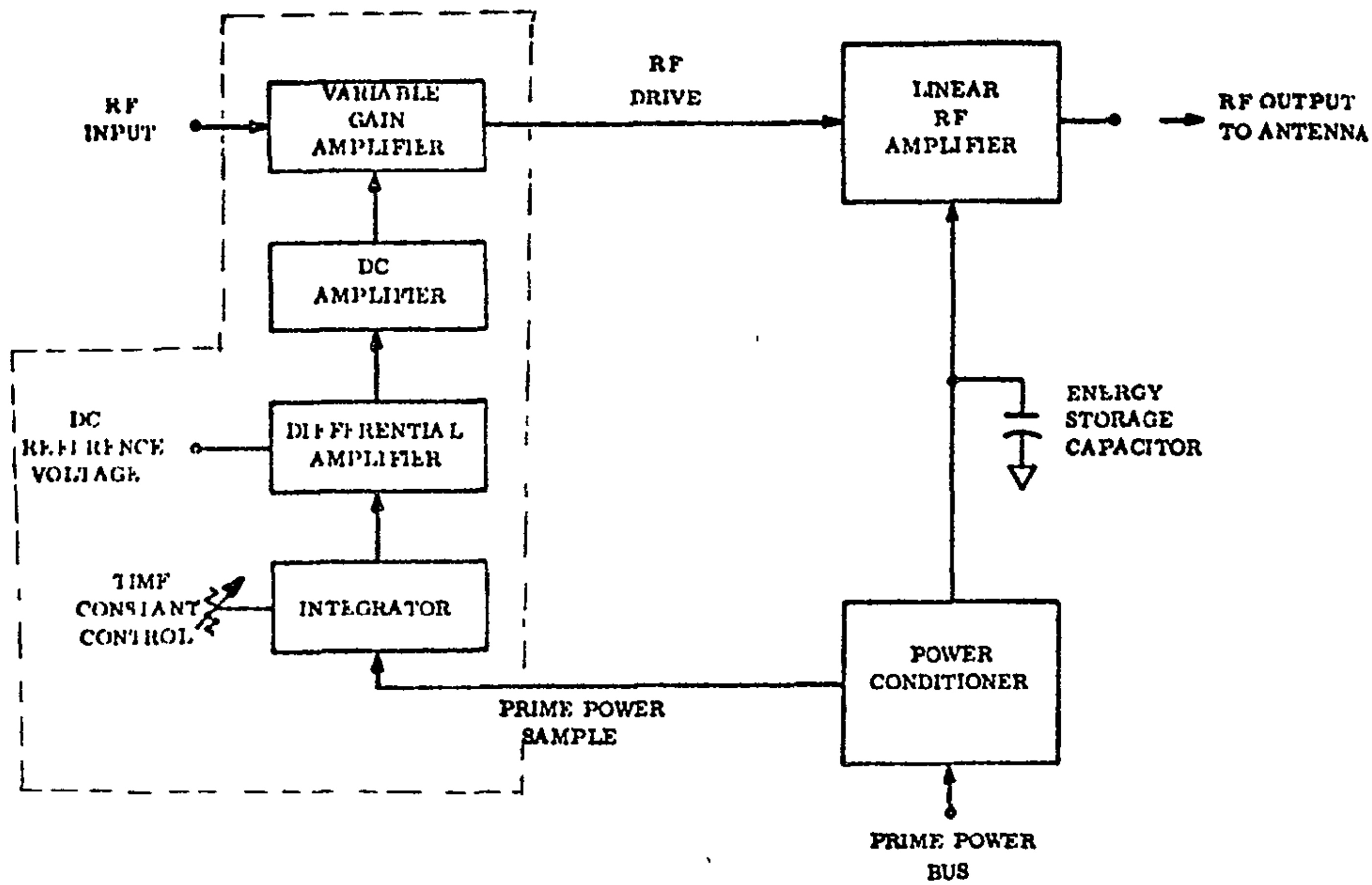


FIGURE 5-5. BLOCK DIAGRAM OF CONTROLLED CARRIER CIRCUIT

of sync peak might be about 2.4 dB. This is not the best circuit operation, however, since the peak power rating of the transmitter would be keyed to the white picture level, and it would be operating well below its rating most of the time, resulting in low efficiency and partially defeating the purpose of the controlled circuit. The alternate proposed circuit would use an average gray level threshold such that the amplifier has a maximum output for that picture level. Then, the sync peak would remain constant for all white pictures below threshold grey (with a corresponding reduction of required dc power but with good efficiency), but would decrease for the larger dc power requirements for dark pictures. In the latter situation, the carrier control circuit would keep the total average power constant. Thus, the amplifier will be operating more closely to its best efficiency point with dark pictures than would the continuous functioning circuit without the threshold feature.

Viewing tests have only been performed for the continuously varying drive signal circuit. Viewing tests should also be performed with the threshold circuit, although there is no evident reason to suspect a significant difference from normal performance.

5.2 VISUAL CHAIN AMPLIFIERS - TASK 2

5.2.1 Visual Chain Driver Amplifier

5.2.1-1 Specifications

A driver amplifier is required in the transmitter breadboard for raising the power output level of the test exciter (5 watts) to the nominal 100 watt level required at the input to the Doherty visual power amplifier. The driver amplifier must also have essentially linear gain characteristics over the TV signal dynamic range and adequate bandwidth to avoid excessive distortion of the television signal. Some degree of dynamic bias control (remodulation) may be required for the purposes of linearity correction and grid current limiting. This task was to design, fabricate, and test a suitable amplifier for incorporation into the transmitter breadboard assembly. Specifications were included in Section 2.3.2-1; additional design factors are:

Electrical

Load Characteristics	Load varies as a function of drive level
Plate Voltage Supply	1500 volts (maximum)
Circuit Configuration	DC grounded plate (tentative)
Test Points	Monitoring points for all significant currents and voltages including rf input and output cavity voltage will be provided.

Thermal

ΔT between adjacent tube seals	100°C maximum

Mechanical

Cavity Construction	Avoid excessive weight
	Avoid excessive thermal detuning effects (or provide for later incorporation of this feature.
Auxiliary Circuit Construction	Package bias or other similar circuitry in a neat fashion. From the standpoint of personnel protection, this circuitry may be mounted as a subassembly in the test power supply rack, but must be designed so that it can readily be removed upon completion of the contract.

RF Connectors	Type N Coaxial
Power Connectors	No exposed voltages greater than 24 volts rms above reference ground. Connector design should permit ease in removing cavity from test setup and dismantling of the cavity.

<u>Personnel Safety</u>

High Voltage	All terminals more than 24vrms above ground will be adequately insulated or shielded to prevent accidental contact by personnel.
RF Radiation	The level of all electromagnetic fields will be maintained below 10 milliwatts per square centimeter at all points accessible to personnel.
Hot Spot Temperature	All points on the outside surfaces of the circuitry which operate at temperatures above $100^{o}C$ will be adequately shielded to prohibit personnel contact insofar as practicable.

5.2.1-2 Design

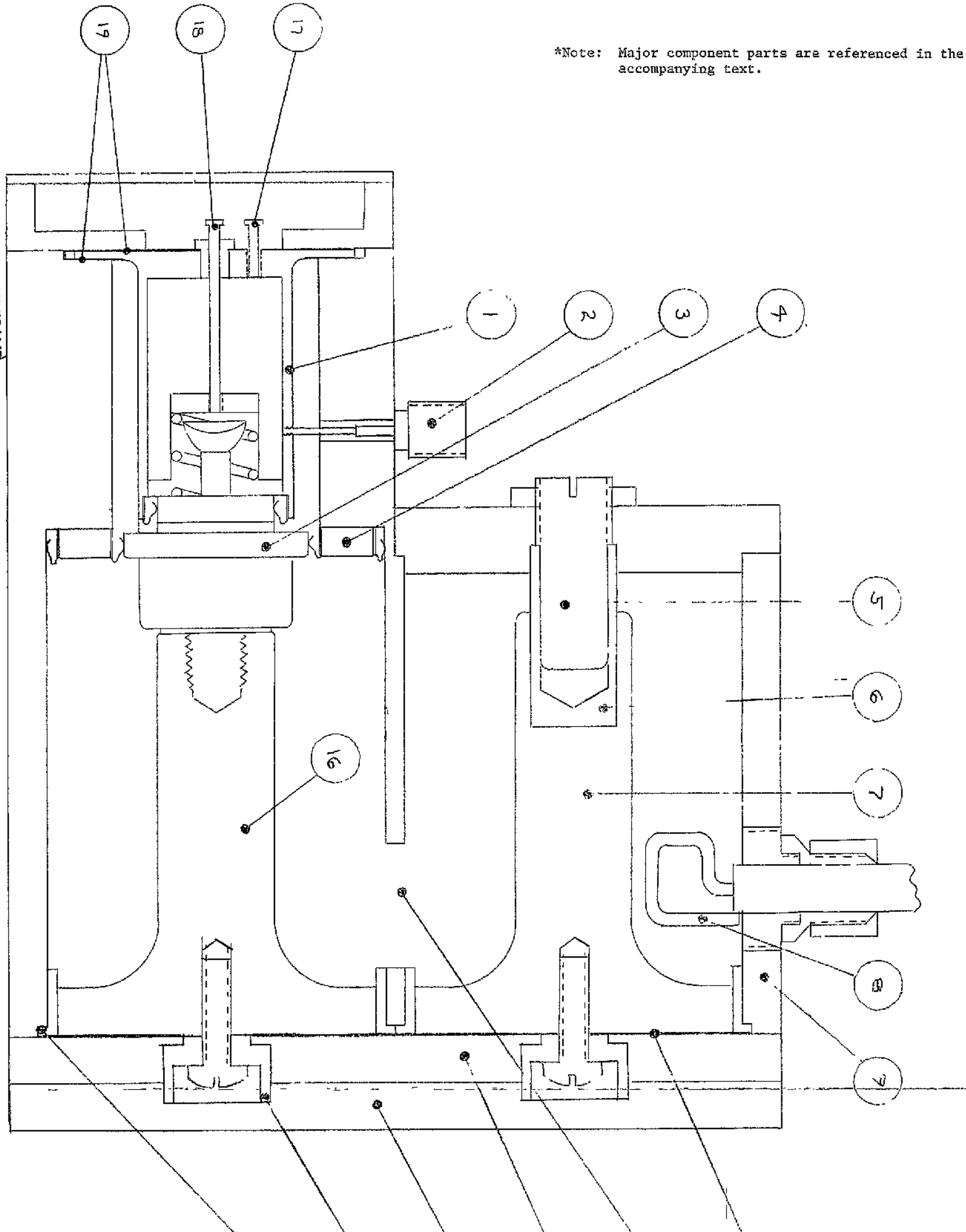
The driver uses a grounded grid circuit as shown in Figure 5-6. The grid is at dc ground as well as rf ground. This assures minimum rf feed through and also aids in multipactor suppression. The cathode circuit is resonated by a low impedance short-circuited transmission line of less than one quarter wavelength. In Figure 5-6, the triode is item 3; the cathode line formed by the case and item 1 is rf shorted by the mica bypass capacitors, items 19. The input power is coupled to the line by a tap of a nominal 50 ohm point (item 2).

The heater voltage is brought in through the center of the cathode line to avoid the RF field. The cathode is common to one side of the heater which is contacted at the cold rf end at item 17. The plate circuit is also a quarter wave short circuited line. The line impedance chosen is a compromise between a small diameter center conductor to minimize the loaded Q and large diameter center conductor to minimize the temperature drop between the anode and case.

A second resonator is coupled to the plate line by an iris (item 11), thus forming

*Note: Major component parts are referenced in the accompanying text.

FOLDOUT FRAME



Cross-section of Visual Driver Amplifier Cavity

FIGURE 5-6

FOLDOUT FRAME 2

a double tuned circuit. A double tuned circuit was necessary to obtain the required bandwidth.

The computed performance of the amplifier is as follows:

Tube Type	ML-8534
Plate Supply Voltage	1.2 kV
Grid Bias	-15 volts DC
Drive Power	6.37 watts
Input Impedance	75 ohms
Output Power	137 watts
Load Impedance	4.05×10^3 ohms
Plate Current	168 ma.
Grid Current	37.5 ma
Gain	13.3 dB
Efficiency	64%

Tube and Cavity Computed Characteristics

Effective Plate Tank Capacitance 3.35 pf
- this is Cgp (2.25 pf) increased 50% due to energy stored in transmission line

Loaded Q = 72.5

1 dB bandwidth single tuned 5.9 MHz

1 dB bandwidth double tuned 18.6 MHz

5.2.1-3 Tube Ratings

The amplifier uses a Machlett 8534 planar triode. The tube type was chosen on the basis of required dissipation, cathode loading, and bandwidth capability. The tube's ratings are:

Maximum DC Plate Voltage	2.5 kV
Cathode Area	0.8 cm^2
Maximum Cathode Loading	0.5A/cm^2

Maximum Grid Current	45 ma
Maximum Seal Temperature	250°C
Cgp	2.25 pf
Cgk	9.5 pf

5.2.1-4 Multipactor Suppression Factors

Both plate lines are operated at 1.2 kV above the case; this will normally prevent multipacting. The gap between the case and both plate lines will experience a peak RF voltage stress of 1.05 kV over 0.55 inches. This would cause multipactor breakdown in a vacuum environment if the gap had no dc bias. The gap between the cathode line and the case will have a maximum RF voltage stress of only 30 volts peak which is below the multipactor threshold.

5.2.1-5 Test Results

The cavity has been cold tested. The cathode line initially resonated at 875 MHz, but has been modified to resonate at 821 MHz, using a tuning capacitor between the case and cathode line near the cathode flange. The plate line resonated initially at 819 MHz; this is too close to the operating frequency to allow for adjustment, with a slug tuner to accommodate tube to tube variations. The plate line impedance will be raised slightly in order to further reduce the resonant frequency. A slug tuner, to bring the frequency up to the proper point, will be located near the cold end of the line.

The initial RF tests indicate that there is no detectable leakage for either input or output cavity. The input match was within 1.8:1, however, the output loop reactance was excessive and prevented optimum coupling. As a result, only 85 watts was obtained in initial tests, using 7 watts drive. The output coupling is presently being modified to include a series resonating capacitor which should correct the output coupling problem.

5.2.2 Doherty Power Amplifier

5.2.2-1 Specifications

The major specifications for the Doherty Visual Channel High Power Amplifier were included in Section 2.3.2-2. Following are some of the supplementary specifications as derived in the Task 1 Systems Study:

Electrical

Load Characteristics	1.2 (maximum) VSWR load
Plate Voltage Supply	2500 volts (nominal)
Circuit Configuration	Based on Doherty Amplifier Circuit with DC grounded plates.
Test Points	Monitoring points for all significant currents and voltages including rf input and output cavity voltage will be provided.

Thermal

Cooling Method	
Anode	Water or conduction (to heat pipe interface) depending on tube type and test fixture availability.
Other tube and cavity elements	Conduction or radiation (no forced air)

Mechanical

Cavity Construction	Breadboard design should be adaptable to space-type hardware with minimal changes. Design features should include:

Ruggedness

Avoidance of excessive mechanical stresses on the tube and other amplifier components due to external forces encountered during normal use, including thermal expansion.

Avoid excessive weight.

Cavity should be readily dismantled for tube replacement, developmental changes, etc.

Avoid excessive thermal detuning effects or provide for a compensation feature.

Auxiliary Circuit Construction	Package bias or other similar circuitry in a neat fashion. From the standpoint of personnel protection, this circuitry may be mounted as a subassembly in the test power supply rack; however, it must be designed so that it can be readily removed for delivery to the customer upon completion of the contract.
RF Connectors	
Input	Type N Coaxial
Output	Mate with ½ height WR 975
Power Connectors	No exposed voltages greater than 24 volts rms above reference ground. Connector design should permit ease in removing cavity from test setup and dismantling of the cavity.
Compatibility with Breadboard Circuit	Designs should be periodically reviewed with the project engineer to assure compatibility with all electrical and mechanical interfaces in the breadboard circuit.

Personnel Safety

High Voltage	All terminals more than 24 rms above ground will be adequately insulated or shielded to prevent accidental contact by personnel.
RF Radiation	The level of all electromagnetic fields will be maintained below 10 milliwatts per square centimeter at all points accessible to personnel.
Hot Spot Temperature	All points on the outside surfaces of the circuitry which operate at temperatures above 100°C will be adequately shielded to prohibit personnel contact insofar as practicable.

5.2.2-2 Amplifier Design

The general aspects of the amplifier design were outlined in the Results, Section 3.2.2. The circuit was shown in that Section (Figure 3-4) and the input and dynamic bias circuits were presented. Since the objective of this task was only to arrive at a design, the balance of the discussion will cover the incidental factors that were encountered.

Circuitry

The amplifier consists of two cavity amplifiers (called the carrier stage and the peak stage) interconnected by coupling the carrier stage output power into the peak stage cavity through a quarter-wavelength transmission line. In effect, the load for this carrier stage output power sppears across the plate circuit of the peak stage cavity. The load thus accepts RF power generated by both stages of the amplifier.

Analysis of circuit performance over the linear range is very complex due to non-linear characteristics of class B and class C amplifiers and the interrelation between the carrier tube and peak tube stages. It was, therefore, deemed appropriate to analyze performance characteristics at a few discrete points, following basic Doherty concepts, and then to experimentally adjust the circuit to give acceptable results.

The anode cavity uses a foreshortened radial cavity design. The outer radius of the anode cavity has been calculated to be 2.79 inches; the inner radius is the same as the tube anode radius. The height of the cavity is 0.437 inches. The width of the iris coupling the peak tube cavity to the antenna load has been calculated to be 3.02 inches; the irises coupling the 2500 watts maximum output of the carrier tube into the peak tube cavity through the half-height $\lambda/4$ waveguide section must each have a width of 2.8 inches. The height of each iris is considered to be the same as the cavity height.

Input Circuit

The hybrid input circuit included in Figure 3-4 will most likely be used, although the alternate approach using a 270° delay line between the peak-tube and carrier-tube cathodes and fed at the peak stage also could be employed, both were shown in Figure 3-5. The hybrid shown inherently provides the required 90° phase delay and also splits the input signal equally. However, the equal splitting is not necessarily a desirable arrangement unless the tube grids are also provided with a "dynamic bias"

voltage which adjusts itself such both tubes are operating under the same bias (and drive) conditions at peak input signal levels.

Dynamic Bias Circuit

The dynamic bias circuit (Figure 3-6) causes the carrier tube to shift from Class B operation for low input signals to Class C operation as the signal increases above the 50% point. The Class C peak stage, on the other hand, is biased so that this tube will not conduct until 50% of peak input voltage is present; as input signal levels continue to increase beyond 50% of the peak value, the bias becomes less negative until, at the peak signal, it has about the same bias (and drive signal) as the carrier tube. An additional advantage of the dynamic bias circuit is that it automatically protects the tubes against excessive grid current and limits grid dissipation during high input drive signal conditions. Figure 3-7 indicated the bias variations on the two tubes as a function of instantaneous signal levels.

Due to the high grid current possible, the circuit should present a low output impedance. A complementary PNP-NPN transistor pair operating push-pull in an emitter follower configuration was selected. The μA773 Integrated Circuit in Figure 3-6 did not work as planned because it did not have sufficient peak output swing capability. A discrete amplifier will be designed in its place. The output stage of the dynamic bias circuit has been breadboarded and some preliminary checks have been made. Excessive phase shift was evident at modulation frequencies neat 5 MHz. Overall phase shift through the amplifier has been minimized by keeping the closed-loop gain low and using UHF transistors where necessary. Because of the high cut-off frequency of the transistors used, it may be necessary to employ parasitic suppression devices on some of the internal connecting wires.

The design of the dynamic bias circuit will be completed after the aural channel

cavities are checked. Fabrication will then proceed, and be followed by component testing.

5.2.2-3 Testing

The amplifier will be tested with the driver and supporting circuitry as outlined in Task 8, Sections 3.8 and 5.8. Operating characteristics that will be measured include:

input VSWR

efficiency

power output

rf drive

dc plate current characteristics

dc grid current characteristics

The above characteristics will be observed as the operating point, load impedance, and cavity tuning adjustments are made.

5.3 AURAL CHANNEL AMPLIFIER - TASK 3

5.3.1 Specifications

The aural amplifier has been designed, fabricated, and partly tested as of the time of this report. Specifications were generated in the Task 1 System Study and were indicated in Section 2.3.3; the following are supplementary specifications for this amplifier:

Electrical

Gain	20 dB
Load Characteristics	1.3 VSWR (max.)
Tube type	GE Y1498
Plate Voltage Supply	1500 volts (typical)
Test Points	Monitoring points for all significant currents and voltages including rf input and output cavity voltage will be provided.

Other electrical objectives were:

- High efficiency and minimization of rf circuit losses
- Design adaptability for later space use
- Avoidance of multipactor discharge phenomena

Thermal

Anode	Water, 0.25 gpm (nominal)
Cavity Parts and Other Tube Parts	Conduction or radiation (no forced air)
Heat Sink Temperature	100oC (max) for conduction cooled surfaces
	60^{o}C (max) for water inlet temperature
ΔT between adjacent tube seals	100^{o}C maximum
Maximum tube seal temperature	300^{o}C maximum

Additional design goals were:

- Minimize electrical insulators in series with heat flow path
- Anode at same electrical potential as spacecraft heat rejection system

Mechanical

Cavity Construction	Breadboard design should be adaptable to space-type hardware with minimal changes - the approach for doing this should be defined in the task final report. Design features should include: Ruggedness Avoidance of excessive mechanical stresses on the tube and other amplifier components due to external forces encountered during normal use including thermal expansion. Avoid excessive weight. Cavity should be readily dismantled for tube replacement, developmental changes, etc. Avoid excessive thermal detuning effects (or provide for later incorporation of this feature.)
Auxiliary Circuit Construction	Package bias or other similar circuitry in a neat fashion. From the standpoint of personnel protection, this circuitry may be mounted as a subassembly in the test power supply rack, however, it must be designed so that it can readily be removed for delivery to the customer upon completion of the contract.
RF Connectors	
Input	Type N Coaxial
Output	Half height WR975 waveguide
Power Connectors RF Test Point	BNC, Female
	No exposed voltages greater than 24 volts rms above reference ground. Connector design should permit ease in removing cavity from test setup and dismantling of the cavity.
Compatibility with Breadboard Circuit	Designs should be periodically reviewed with the project engineer to assure compatibility with all electrical and mechanical interfaces in the breadboard circuit.

Other mechanical goals were:

- No electrical hazards during test and evaluation
- No use of exposed high potential surfaces

- No stresses due to temperature differentials between tube electrodes
- Ability of amplifier output port to interface with a half - height waveguide system.
- Use of materials which are lightweight, give long life operation in space, and have minimum outgassing characteristics.
- Ease of adjustment of coupling and tuning
- Ease of assembly and disassembly for possible examination and/or alteration
- Ability to alter any circuit element without scrapping large, costly assemblies.

Personnel Safety

High Voltage	All terminals more than 24vrms above ground will be adequately insulated or shielded to prevent accidental contact by personnel.
RF Radiation	The level of all electromagnetic fields will be maintained below 10 milliwatts per square centimeter at all points accessible to personnel.
Hot Spot Temperature	All points on the outside surfaces of the circuitry which operate at temperatures above 100°C will be adequately shielded to prohibit personnel contact insofar as practicable.

5.3.2 Selected Approach

The development of the Doherty visual power amplifier is the main consideration of the overall breadboard transmitter program. The otherwise relatively straightforward design of the CW amplifier used in the aural FM signal channel was, therefore, directed in part toward solving the problems common to the Doherty design. It appeared that no significant operating degradation in the aural design would result if the design also met the Doherty requirements. The tube selected for the Doherty is also the best device for the aural stage, and the use of a dc grounded anode configuration for greater ease in applying heat pipe cooling is an overall advantage in both aural and visual amplifiers. (The visual amplifier may be operated in a dc grounded grid.) (Configuration based on more recent design information.)

Consideration was given to potential high power breakdown and cooling requirements as would arise in a space transmitter, although it was not considered feasible to

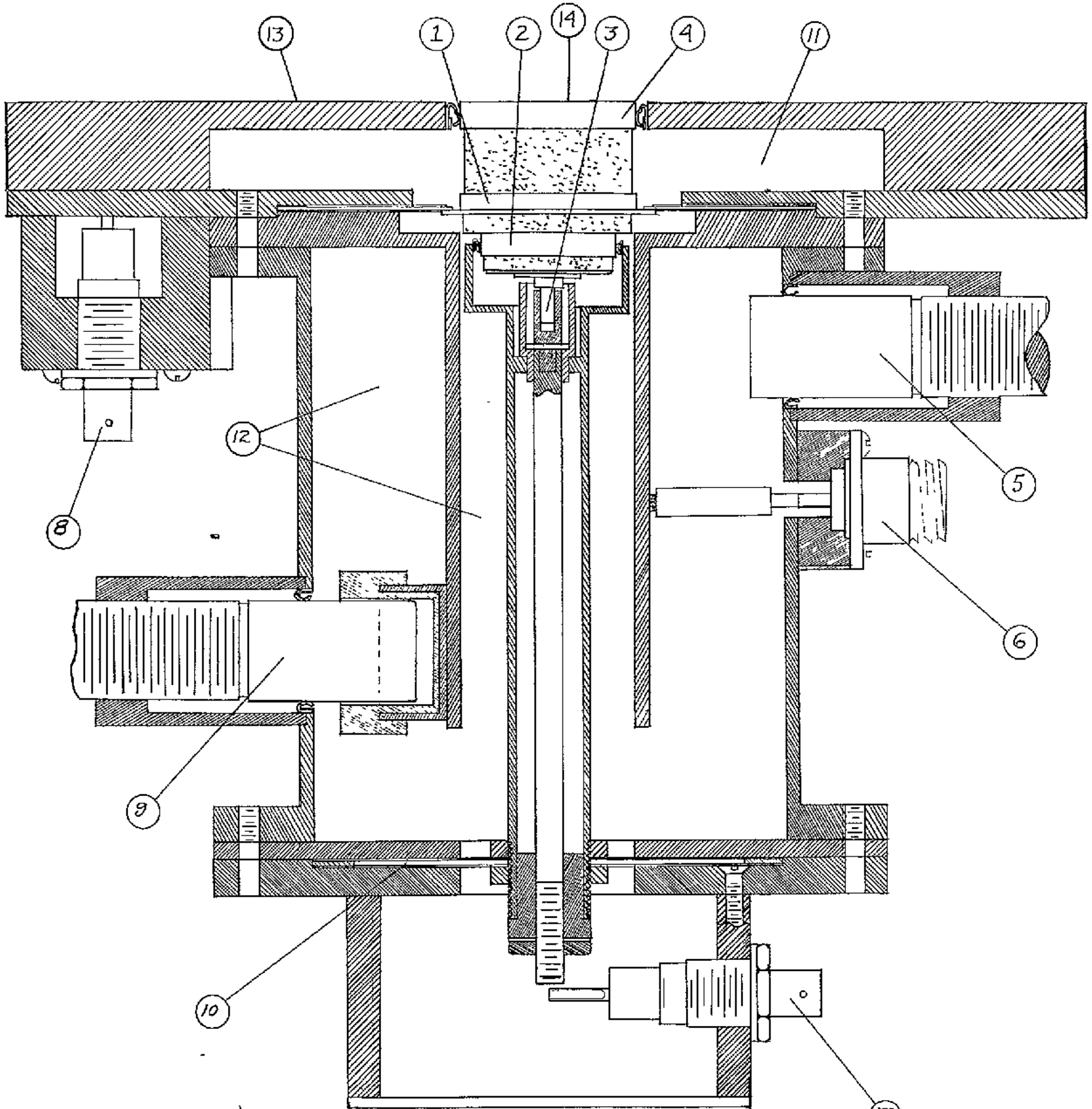
incorporate all of these features in the first cavity design. These techniques were given some consideration in the visual driver cavity amplifier (Sections 3.2.1 and 5.2.1) where the tube used was a more standard production type and less subject to be a variable factor.

5.3.3 Circuit Design

Perhaps the simplest circuit applicable to planar triodes like the Y1498 tube in the UHF region of the spectrum is a grounded-grid circuit employing coaxial resonators. This circuit was presented in simplified form in Figure 3-9, and a detailed cross-section of the cavities is in Figure 5-7.

The tube interelectrode capacitances load the resonant transmission line sections, requiring that the cavity lines be shorter than $\lambda/4$ or $3\lambda/4$. The line X_c is = $Z_o \tan \beta \ell$, where β= the phase constant in radians per unit length. In the present case, with a Y1498 tube and f_o = 829.75 MHz, the foreshortening of the cavity necessitated by the grid plate capacitance reduces the length of the output cavity line to a dimension less than the diameter, making the line, in effect, a flat "pill box" shape, better described as a radial transmission line cavity. Similarly, the grid-cathode capacitance is of such magnitude as to make the design of a $\lambda/4$ grid-cathode line impractical, so a $3\lambda/4$ coaxial cavity is used for the cathode input circuit.

The simplified schematic of Figure 3-9 showed the necessary dc blocking capacitors as used. The most convenient location for low-loss rf capacitors in series with the electrodes was at the flat surface in the plane of the grid and at the short-circuited end of the folded grid-cathode line. The inner section of the amplifier cavity cross-sectional drawing, Figure 5-7 shows the hardware realization of the bypass capacitors in the circuit. Referring to this figure, a variable piston type capacitor(9) has been incorporated in shunt with the cathode line at a high impedance point for tuning. A second movable plunger (5) intercepts a portion of the rf magnetic flux which links the input coupling loop, thereby providing a means of adjusting the coupling.



FOLDOUT FRAME 1

Figure 5-7. Cross Section of Aural Channel Amplifier

KEY

ITEM	DESCRIPTION
1	GRID CONTACT SURFACE
2	CATHODE CONTACT SURFACE
3	HEATER CONTACT PIN
4	ANODE CONTACT SURFACE
5	INPUT COUPLING ADJUSTMENT PLUNGER
6	RF INPUT CONNECTOR
7	HEATER AND CATHODE POWER CONNECTOR
8	GRID BIAS CONNECTOR
9	INPUT TUNING PLUNGER
10	CATHODE BYPASS CAPACITOR
11	ANODE-GRID CAVITY RESONATOR
12	CATHODE-GRID CAVITY RESONATOR
13	MOUNTING SURFACE AND CAVITY HEAT SINK INTERFACE
14	TUBE ANODE HEAT SINK INTERFACE

FOLDOUT FRAME 2

Initial tests on the amplifier will be conducted using a coupling loop to extract power from the anode cavity. For later system tests, an iris in the wall of the cavity will couple the anode cavity directly to the output waveguide, which transfers the output power to the load.

5.3.4 Anode-Grid Test Cavity for Y1498 Tube

In order to determine the dissipative loading effect of the tube on the tank circuit, and to investigate the contact properties of titanium electrodes, a "cold" cavity was designed as a grid-plate tank circuit for testing. Since it was not intended to apply dc power to the tube, no dc blocking capacitors were incorporated. The cavity was machined from half hard brass and fitted with Instrument Specialities 97-380 spring finger stock to effect contact with the anode ring. The grid flange was clamped. Simulated anode and grid electrodes were machined from brass for comparison measurements using the same electrode geometry and interelectrode capacitance. The cavity-tube combination was evaluated in terms of its Q as determined from the shape of its unloaded resonance response. The unloaded resonance response was measured in terms of the transmission characteristic between two small loosely coupled loops located on opposite sides of the radial cavity at points of maximum rf wall currents. The cavity resonance occurs at approximately 1 GHz with the first two Y1498 tubes received. Initial measurements showed a Q of 150 to 300 with the tube in place and about 900 to 1000 with the simulated electrodes. The Q and transmission coefficient with tube in place were erratic and varied considerably with clamping pressure and minor changes in position. As received, the tube electrode surfaces had a coarse crystalline appearance. When the anode ring was polished, the Q increased from about 120 to about 300. The cavity parts were then plated with 0.5 mil of silver and covered with 25 x 10^{-6} inch of gold. The tube electrodes were plated with about 0.5 mil of gold over a nickel strike. When reassembled, the Q of the cavity-tube combination was about 800. A number of the anode contact spring fingers were broken in removing the tube due to a siezure between the gold plated springs and the gold plated anode contact. The Q of the plated cavity with the dummy tube in place was 950.

The vacuum envelope of a plated electrically defective tube was intentionally pierced to observe the resultant effect on the Q of the cavity-tube combination. There was no noticeable change in Q.

The test cavity was then heated to determine drift, from $25^{\circ}C$ to $125^{\circ}C$, its resonant frequency increased by about 3.5 MHz, which will be of no concern for this amplifier.

5.3.5 Space Design Factors

There is some concern about possible rf breakdown in the present design if it were to be used under space conditions. The input cavity should be free from multipacting; however, the output cavity dimensions are such that occurrence of multipactor breakdown is likely. The use of a biased electrode in the anode cavity is proposed as a means of suppressing any such tendencies. This electrode would be disc shaped, parallel to the anode surface of the tube, and could be connected to the plate supply potential.

Ionizing breakdown (dc and/or rf) could also be a problem due to the possible entrapment of air in the stacked disc mica capacitor assemblies used as grid and cathode rf bypasses. Either a proper bakeout procedure or the use of improved void-free capacitor assemblies may be a suitable solution to this potential problem. The latter approach may require development of effective rf bypass capacitor assemblies, probably involving metallizing of the dielectric surfaces.

5.4 RF COMPONENTS - TASK 4

5.4.1 High Power RF Components

The completed assembly was shown in the photograph of Figure 3-11. After assembly additional tuning was performed to improve VSWR in the passband. This resulted as:

	Before Tuning	After Tuning	
VSWR			
Visual Channel	1.26 to 1.30	1.10	
Aural Channel	1.15	1.10	
Insertion Loss	0.1 dB (Est.)		
	Length	Width	Height
Dimensions (Excl. Flange Hts.)			
Filter/coupler assembly	23.9	20.0	2.7
To top of cavity	---	---	17.3
To top of couplers	---	---	5.1
Hybrid	24.0	20.0	2.7

Dimensions and weights of these units for spacecraft use can be reduced. The mechanical techniques used in these units are basically those of ground type equipment, which is an acceptable approach for an experimental breadboard transmitter.

5.4.1-1 Color Notch Filter Design

The color subcarrier image notch filter is a single-tuned circuit design, following current television design practices and the recommendations of previous studies (Sec 5.3.2 of Reference 2). Since the width of the dual waveguide assembly is already about 20 inches, it was decided to use a top-coupled cavity, which could be configured to lie parallel to the waveguide between visual amplifier and load in a spacecraft design. This arrangement would result in a filter assembly height of less than 6 inches (including the waveguide to which it is coupled) and a length of about 20 inches. Several configurations, including the basic "T" top wall coupled configuration fabri-

cated for the transmitter breadboard are indicated in Figure 5-8.

The other four configurations show three folded versions, any one of which could be used for a flight system.

A. Specifications

In addition to the specifications of Section 2.3.4-1, the following supplementary factors apply:

- Electrical:

Insertion Loss for the visual channel	0.10 dB (maximum allowable) at 825.25 MHz and averaged over 824.0 MHz to 829.5 MHz, more than 20 dB at 821.67 MHz

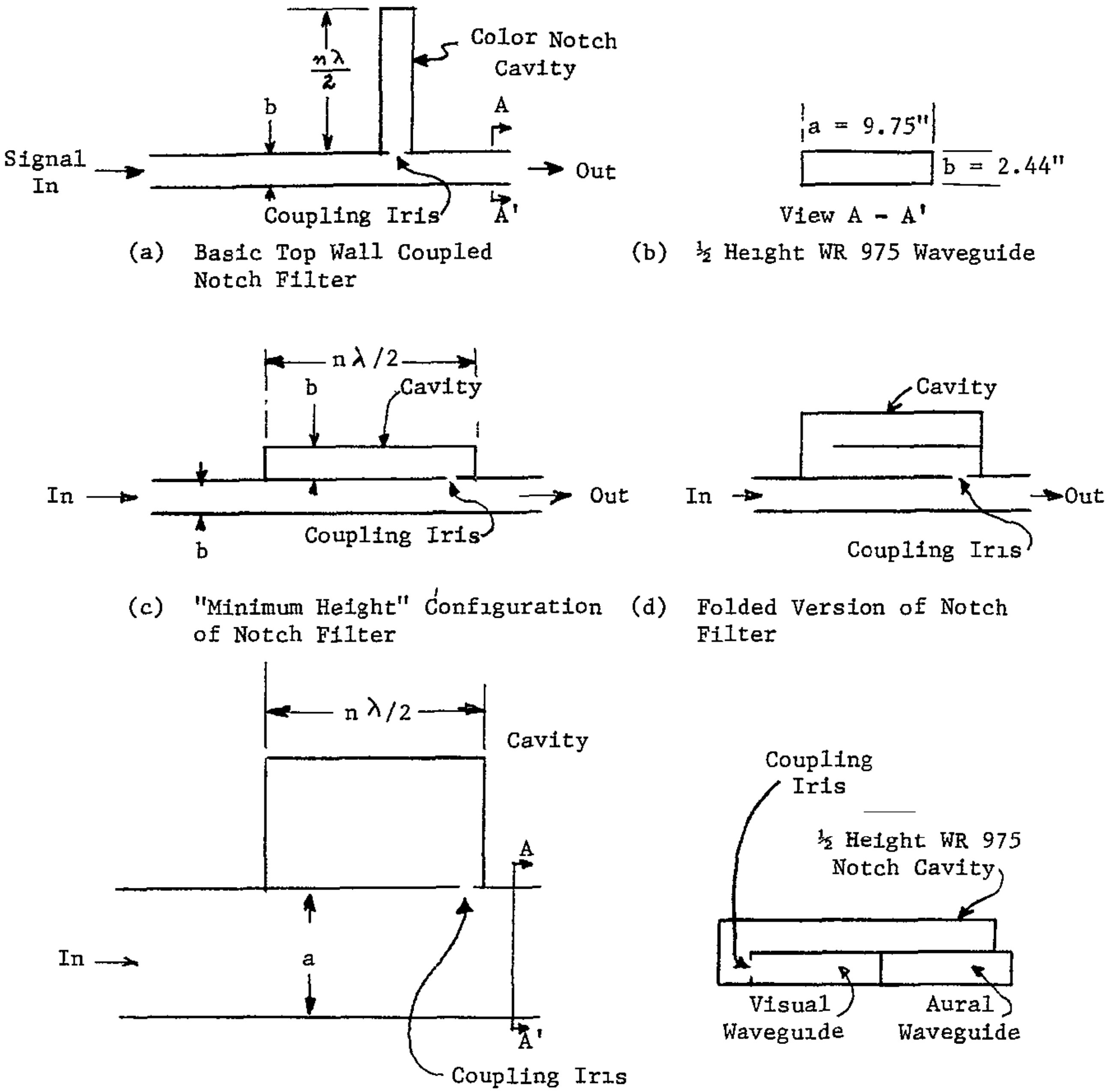
- Mechanical

General Arrangement	Attach to upper broad wall of guide
Length	Minimize, 28 inches maximum axial length (24 inches, typical)
Flanges	One-half height WR975 flat face, tolerances should permit application of flange-to-flange connections without necessity for auxiliary rf "gasketing" between flange faces.
Material	Waveguide and most of structure to be aluminum alloy construction.
Finish	Protective film of aluminum parts as described in MIL-C-5541, silver plate cuprous alloy materials, other materials per good commercial practice.
Cooling	Convection, ambient air.

- Environment:

Ambient Temperature	18°C to 35°C
Relative Humidity	Less than 80%

The waveguide assembly will contain a dual directional coupler in each channel to allow monitoring of power output, reflected power, and load VSWR The color image filter is located between the output cavity of the final amplifier stage and these monitoring directional couplers, its performance is included in the overall performance of the visual amplifier chain.



(a) Basic Top Wall Coupled Notch Filter

(b) ½ Height WR 975 Waveguide

(c) "Minimum Height" Configuration of Notch Filter

(d) Folded Version of Notch Filter

(e) Side-Wall Coupled Notch Filter

(f) Side-Wall Coupled Notch Filter with Filter Cavity Folded Over Dual Waveguide Run (Cavity is coupled to visual waveguide only Head on view of visual and aural waveguides shown as in (b) cross-section view).

FIGURE 5-8. NOTCH CAVITY CONFIGURATIONS

The basic circuit for the filter is a single tuned parallel-resonant circuit in series with the waveguidr run, as shown in Figure 5-9. Values of parallel resonant circuit L and C are such that loaded Q is very high, and the circuit provides a high attenuation at the côlor subcarrier image frequency. It becomes a very low impedance at frequencies within the visual transmitter pass band and offers little loss to these frequencies. A simple analysis based on the filter circuit of Figure 5-9 is included in Reference 14.

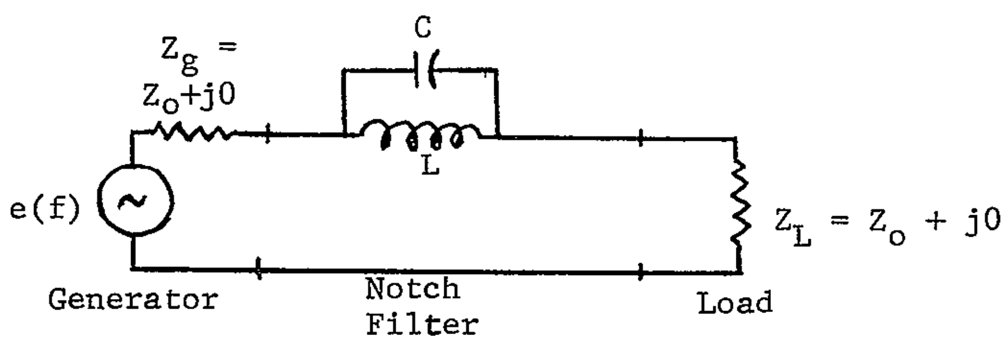


Figure 5-9. Notch Cavity Circuit

The analysis indicated an unloaded Q of 18,200 is desirable to obtain a 20 dB rejection at 821.67 MHz but a negligible loss at the 825.25 MHz carrier frequency. The Q is attainable with a half-height WR975 dimensioned cavity Details on the design of iris couplings and band reject cavity filters are given in Section 5.10 and Chapters 8 and 12 of Reference 9. Selection of the appropriate relations for the particular case in a given requirement can be derived from information given in this excellent reference.

In a speacecraft version considerable improvement in thermal characteristics could be provided if the notch filter is mounted against the broad wall of the visual waveguide as in Figure 5-8c. This also gives rise to a weight reduction since the waveguide and cavity can now share a common wall. Additional weight can be saved by machining away large portions of the waveguide wall thickness leaving a thin-skinned, ribbed member as required for rf, structural, and thermal conduction characteristics. The lower broad wall surface will be attached to a heat sink for thermal control in the spacecraft version.

Measured performance of the filter for TV channel 73 is:

Notch attenuation	20 to 23 dB
VSWR at visual carrier	1.23
Loss at Visual carrier (calculated from VSWR)	0.1 dB

A tuner is required in the overall assembly to achieve an acceptable VSWR, the introductory paragraph of this section indicated a 1.10 VSWR with tuning.

5.4.1-2 Directional Couplers

The reflectometer-type directional coupler has adequate performance in the UHF television band and was chosen for this application primarily on the basis of compactness. Two sets of directional couplers are included in the waveguide assembly of Figure 3-11, one set in each of the two RF channels. Like all the waveguide components, these are fabricated in half-height WR975 waveguide, and the pair have a common narrow wall. Each set of couplers includes a forward and a reverse coupler. The color notch filter precedes the coupler in the visual channel, and the aural amplifier feeds directly into the coupler in the aural channel; outputs feed into the 3 dB hybrid. Some of the pertinent specifications for the directional couplers are·

- Electrical

Coupling ratios	For the frequency range 824.0 MHz fo 830.0 MHz
a. Forward Visual Coupler	-56 dB $\pm$ 0.2 dB
b. Reverse Visual Coupler	-46 dB $\mp$ 0.2 dB
c. Forward Aural Coupler	-36 dB $\mp$ 0.2 dB
Directivity (all Directional Couplers)	30 dB (minimum) for the 824.0 MHz to 830.0 MHz frequency range
Directional Coupler RF Output Fittings	Type N - Female
Operating Transmission Range	Above specifications shall apply for convection cooling with 18 to 35^{o} ambient temperature and up to 5.0 kW peak synchronizing visual power and 0.5 kW CW aural power.

- Mechanical

General Arrangement	The directional couplers will be a part of the output waveguides from the two output amplifiers. No components are to be attached to the lower broad wall of the waveguide assembly.

An illustration of the basic form of the coupler was shown in Figure 3-12a, repeated here for convenience. A small loop is introduced into the waveguide; each end of

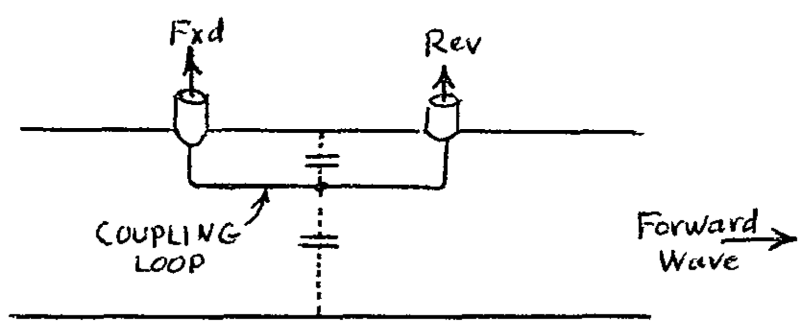


Figure 3-12a. Basic Reflectometer Type Directional Coupler

the loop is connected to loads (or external instrumentation) by means of coaxial lines of some convenient impedance Z_o. The loop area and orientation with respect to the waveguide axis controls coupling to the magnetic field within the waveguide. Coupling to the electric field within the waveguide is also made with the loop. By adjusting loop size and shape, with a particular load Z_o at either end, and with $C_1 \gg C_2$, the currents induced by electric and magnetic field can be made to add in one load and cancel in the other for waves propagating in a single direction in the waveguide. In the case shown, the Forward wave sample couples to the left hand coaxial post. For this condition of coupling, a wave traveling within the waveguide in the opposite or Reverse direction couples to the right hand port. With proper adjustment, a particular port will have over 30 dB ratio in its coupling to Forward and Reverse waves. This "Directivity" allows measurement of Forward and Reverse wave amplitudes, from which VSWR can be calculated for a particular value of coupling. The coupler can be used with a thermistor mount type microwave power meter to measure power in the wave. Figure 3-12b showed a more practical arrangement for fabrication. Here the forward and reverse monitors are separate units to provide better isolation of operation.

The couplers are included in the photograph of Figure 3-11. The coupler assemblies are mounted on the load side of the filter so that filter effects will be included in the signal output sample. A second set of couplers is mounted on the aural channel waveguide.

Measured performance of the coupler assembly for TV channel 73 is as follows:

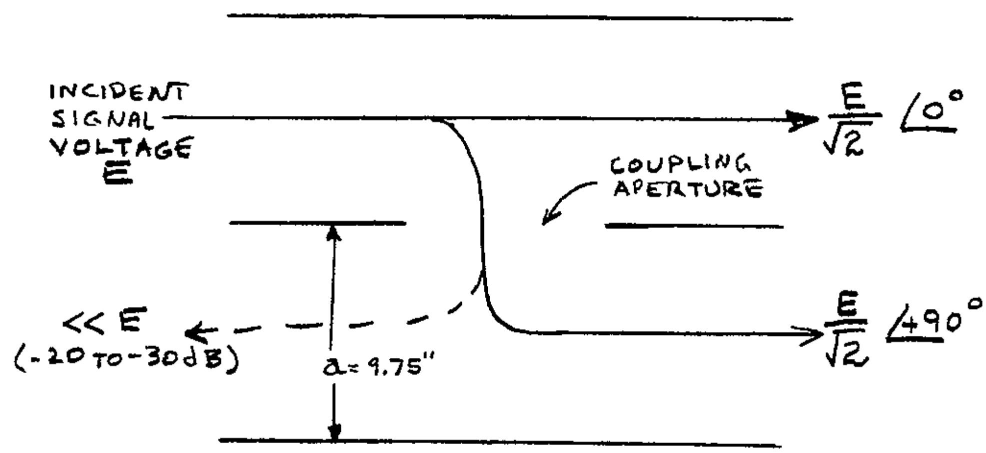
	Coupling dB	Directivity dB
Visual Forward	50.2	30 dB
Visual Reverse	40.1	30 dB
Aural Forward	40.2	30 dB
Aural Reverse	40.2	30 dB

5.4.1-3 3-dB Sidewall Hybrid

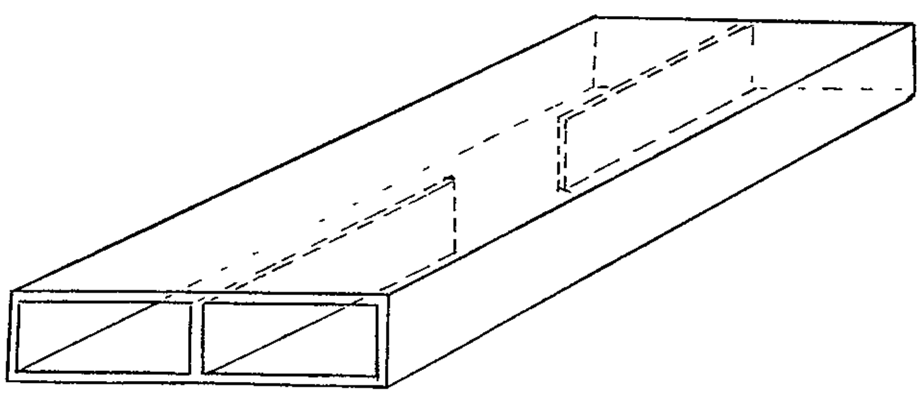
The hybrid is a 3 dB short slot type coupler fabricated in one half height WR975 waveguide. The flanges used to couple the hybrid to mating components are of the dual flange type which permits the design of the hybrid to have shortest possible axial length. Detailed specifications for the hybrid were given in Section 2.3.4-1; some supplementary specifications are:

Electrical	
Sliding load termination VSWR	1.03 (maximum)
Mechanical	
Waveguide	half height WR975
Length	Minimize, 24 inches maximum axial length
Flanges	Dual one half height WR975 common narrow wall, flat face, tolerances should permit applications of flange to flange connections without necessity for auxiliary rf "gasketing" between flange faces.
Materials	Waveguide and majority of structure to be aluminum alloy construction.
Finish	Protective film on aluminum parts as described in MIL-C-5541, silver plate cuprous allow materials, other materials per good commercial practice.
Cooling	Convection, ambient air
Environment	
Ambient Temperature	$18^{o}C$ to $35^{o}C$
Relative Humidity	less than 80%

Detailed design of a sidewall-coupler is described in the literature[19]. It consists of two parallel waveguides sharing a common wall which contains a coupling aperture. By properly dimensioning the aperture, 3dB coupling is obtained so that a wave entering either input port is divided equally and transmitted to two output ports. The other input port is isolated from the first and receives little power (typically -20 dB). Additional tuning elements are normally incorporated to give increased bandwidth and as means of optimizing performances of the hybrid. Figure 5-10 is a sketch of the hybrid.



a) TOP VIEW OF SIDEWALL HYBRID



b) BASIC SIDEWALL HYBRID CONSTRUCTION

FIGURE 5-10. 3-dB SIDEWALL HYBRID

Measured performance of the half height WR975 sidewall hybrid is given below.

Coupling	30 dB
Isolation	33dB, 824.0 to 830.0 MHz
VSWR	1.03 at Band Center 1.07 at Band Edges

5.4.1-4 Waveguide to Coax Transitions

The transition is a dual unit which is used to couple the two waveguide outputs of the 3 dB hybrid to their respective coaxial dummy loads. The dual waveguide section used has a special dual waveguide flange which permits mating with the 3 dB hybrid output. Specifications were indicated in Section 2.3.4-1; supplementary ones are:

Mechanical

General Arrangement	See Figure 3-11. No components should be attached to the lower broad wall of the waveguide assembly; use half height WR975 waveguide.
Length	Minimize, 12 inches maximum axial length (10 inches, typical).
Flanges	Dual one-half height WR975 common narrow wall, flat face, tolerances should permit application of flange-to-flange connections without necessity for auxiliary rf "gasketing" between flange faces.
Finish	Protective film on aluminum parts as described in MIL-C-5541, silver plate cuprous alloy materials, other materials per good commercial practice.
2.7 Cooling	Convection, ambient air.

Environment

3.1 Ambient Temperature	18°C to 35°C
3.2 Relative Humidity	Less than 80%

Each transition section contains a conventional T-bar coupling between half-height WR975 waveguide and a 1-5/8 inch coaxial lines. The intrinsic bandwidth of the transition is greater than that of a television channel. Measured performance is:

VSWR	1.03
Bandwidth	824.0 to 830.0 MHz

5.4.2 Vestigial Sideband Filter

The vestigial sideband filter is to be designed to shape the transmitted video rf signal in compliance with U.S. television standards as outlined in EIA Standard RS-240.[3] Additional requirements are for minimal size and weight consistent with moderate insertion loss. Lightweight is considered more significant than loss since the VSB filtering will be accomplished at a low power level, at a few watts where considerable loss can be tolerated with little impact on the efficiency of the overall transmitter. Its construction will utilize a TEM wave structure such as stripline or coaxial lines. Basic specifications for the VSB filter were given in Section 2.3.4-2; supplementary ones are:

Electrical

Operating Frequency	TV Channel 73 (824 to 830 MHz)
Bandpass Characteristics	Per Figure 2-3
Input Power	10 Watts (max.)
Insertion Loss	3.0 dB (max.) from (f_o - 0.75) MHz to (f_o + 4.2) MHz
VSWR	1.5:1 (max.) from (f_o - 0.75) MHz to (f_o + 4.2) MHz

Mechanical

Cooling	Design for conduction cooling of all elements
Construction	Design should be readily adaptable to rugged, lightweight construction for spacecraft use. Minimum size is also desirable.
RF Connectors	Coaxial, Omni Spectra OSM or Equivalent
Compatibility with Breadboard Circuit	Designs should be periodically reviewed with the project engineer to assume compatibility with all electrical and mechanical interfaces in the breadboard circuit.

Environment

Ambient Temperature	18°C to 35°C
Relative Humidity	Less than 80%

The filter design makes use of the phase sensitive properties of a 3 dB quadrature hybrid as was shown in the block diagram of Figure 3-13. This filter will give sharp skirts without the use of a large number of resonant cavities.

In the two quadrature hybrid with the two tuned circuit terminations, the magnitude of the reflections are unity; if the relative phases of the reflections are in phase, the hybrid will pass all of the incident energy. But if the phases of the reflections are 180° relative to each other, all the energy is reflected back into the source.

The design of this filter is based on Reference 5 and uses several equations from that document. Filter voltage response is given by the equation,

$$R = \frac{2j}{k_3 + k_4}$$

where k_3 and k_4 are the reflection coefficients at ports 3 and 4 of the hybrid network.

The reflection coefficientis magnitudes and phases can be determined for various terminations, and this information can be used to determine k_3 and k_4, and thus the overall filter response. Single and double tuned cavities are of specific interest. An analysis showed that as long as the Q's of the terminations are large, the filter is not dependent on Q.

The simplest filter would utilize single tuned cavities as reactive terminations. However, the bandwidth of such a filter is not sufficient to give the required 20 dB of attenuation over the 4.5 MHz bandwidth. In order to investigate this filter for feasibility, the phase variations of the single cavity termination was determined for various values of coupling, T. Then a duplicate transparancy overlaid the first series of plots. By sliding the graphs relative to each other and visually comparing the curves, the filter characteristic can be readily recognized. Maximum attenuation occurs for maximum phase difference for the curves. The phase response for the single cavity is given in Figure 5-11. This method of analysis showed that two single cavity reactive terminations are not sufficient to give the required 20 dB of attenuation over a 4.5 MHz bandwidth.

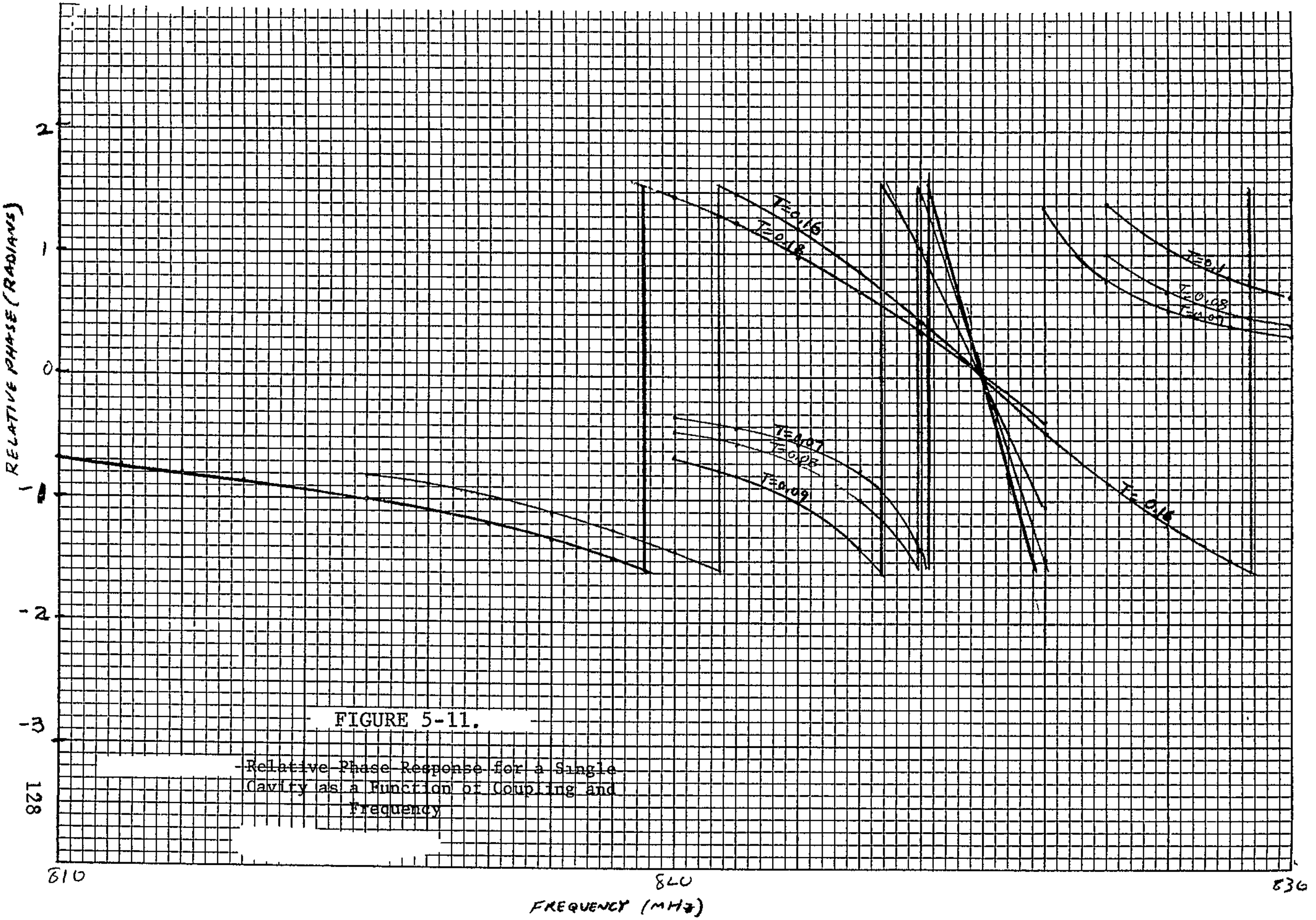


FIGURE 5-11.

Relative Phase Response for a Single Cavity as a Function of Coupling and Frequency

The next filter considered used a single tuned cavity at one port of the hybrid and the double tuned cavity at the second port as was shown in Figure 3-13. The phase response of double tuned cavity was plotted for various values of coupling. The results were given in Figure 3-14. This configuration should give the required response.

An experimental filter was fabricated, as was shown in Figure 3-15, to verify theoretical conclusions. This filter was fabricated in a strip transmission line form with overall dimensions of 6 x 10 x 3/4 inches. The ground planes were fabricated from 1/8 inch aluminum plate and the filter structure was made from one mil brass shim stock. Four 1/8 inch inch polystyrene plates were sandwiched to fill the volume between the ground planes and to support the filter structure. Polytyrene has similar electrical characteristics to PPO material, which a flight model filter would use.

Initial tests on the filter showed the rejection band to be broader than predicted and the filter skirts to be less steep than predicted. Losses were also more than expected. These results indicate that the materials used for the conductors are too lossy. Measurements are currently underway to measure the Q's of the resonators and compare these with the theoretical values. Silver stock is available for testing and comparison.

5.5 MONITOR AND PROTECTIVE CIRCUITS

5.5.1 Requirements

The basic requirements for the monitor and protective subsystem were outlined in Section 2.3.5. Specific circuits required are an "electronic crowbar" for the plate (anode) high voltage supply of the high efficiency visual output amplifier. As an integral part of the crowbar protection a fault sensing and control logic circuit is required to sense faults potentially harmful to the final amplifier components, fire the crowbar element, and control the power supply to limit fault energy.

In addition, a VSWR trip was required for RF fault protection. The output of the task was to provide a breadboard crowbar design, along with associated monitoring, control, and protective circuitry to complete the fault protection system.

The crowbar protective system will be capable of maintaining the fault arc energy below a level of 5 joules in the case of an arc in the high efficiency final amplifier tubes This value has been established as a reasonable limit of the energy the planar triode in the amplifier may safely endure without permanent damage or disability. The power conditioner will contain an L-C section filter to act as an energy storage element providing sync peak power for the transmitter. The present engineering estimate of this filter is a 1.6 Hy choke and a 44 μF capacitor. The crowbar element with 2.5 kV must be capable of handling an energy of

$$W_c = 1/2\ CV^2$$

$$= 137.5 \text{ joules}$$

Although spark gaps were available with 200 joule ratings, the GP12BV (manufactured by EG&G) gap was selected because of the possibility of operation at higher voltage levels or with a larger filter to further reduce ripple. This particular gap is a vacuum version of the GP12A and has an operating range of 1 kV to 50 kV in air with a peak current capability of 100,000 amperes. It requires a trigger potential of 20-30 kV and will fire after a delay of only .05 μsec. The total dissipation rating of the gap is 2500 joules.

The general power supply - crowbar-protected load configuration is shown in Figure 5-12.

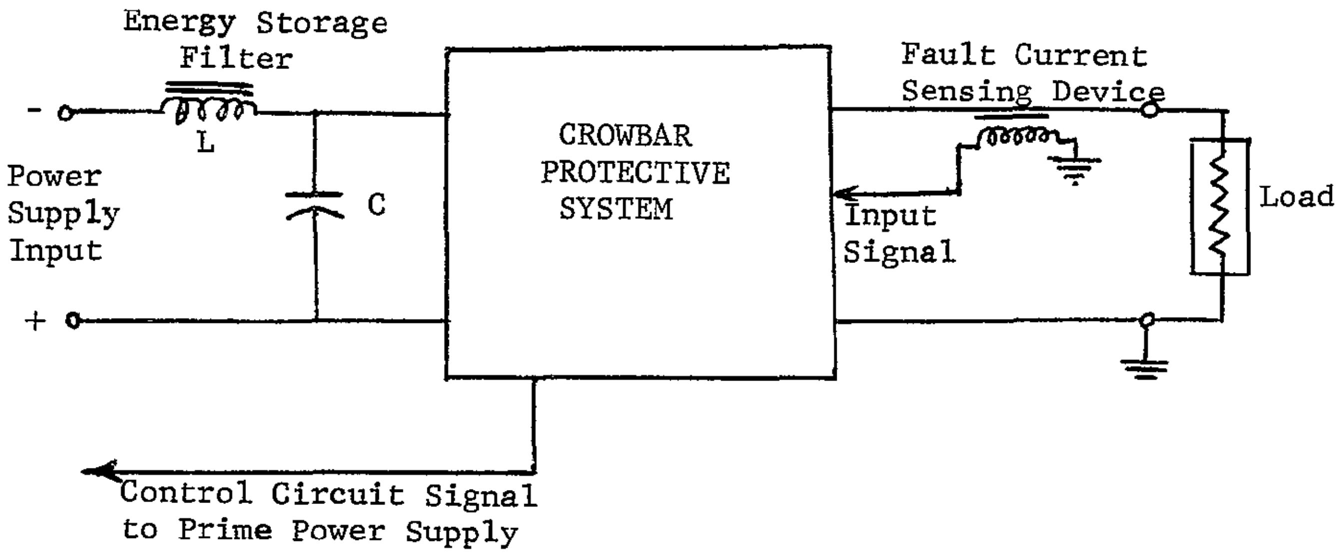


Figure 5-12. Power Supply - Crowbar - Load Diagram

This circuit was analysed[15] to determine the division of energy when an arc appears in the load (protected tube) and the crowbar gap is triggered. The crowbar gap can be triggered from the current transient to the load, and generally the circuit can divert the current in well under 2 microseconds. In the case computed, the fault energy was about 0.1 joule, well below a level that would be injurious to the transmitter tubes.

In order to realize this performance, the internal impedance of the storage capacitor must be less than about 250 ohms to insure a minimum keep-alive current In addition, the storage capacitor must be of a quality that will permit a large transient current. Repetitive triggering of the arc is built into the circuitry to insure that the capacitor will not recharge, from energy stored internally in the power conditioner and in the filter choke, after initial arc extinction.

5.5.2 Trigger, logic, and control circuits

The crowbar trigger, logic and control circuitry, shown in Figure 5-13, consists of a threshold circuit employing Q_1 to trigger the monostable multivibrator that includes

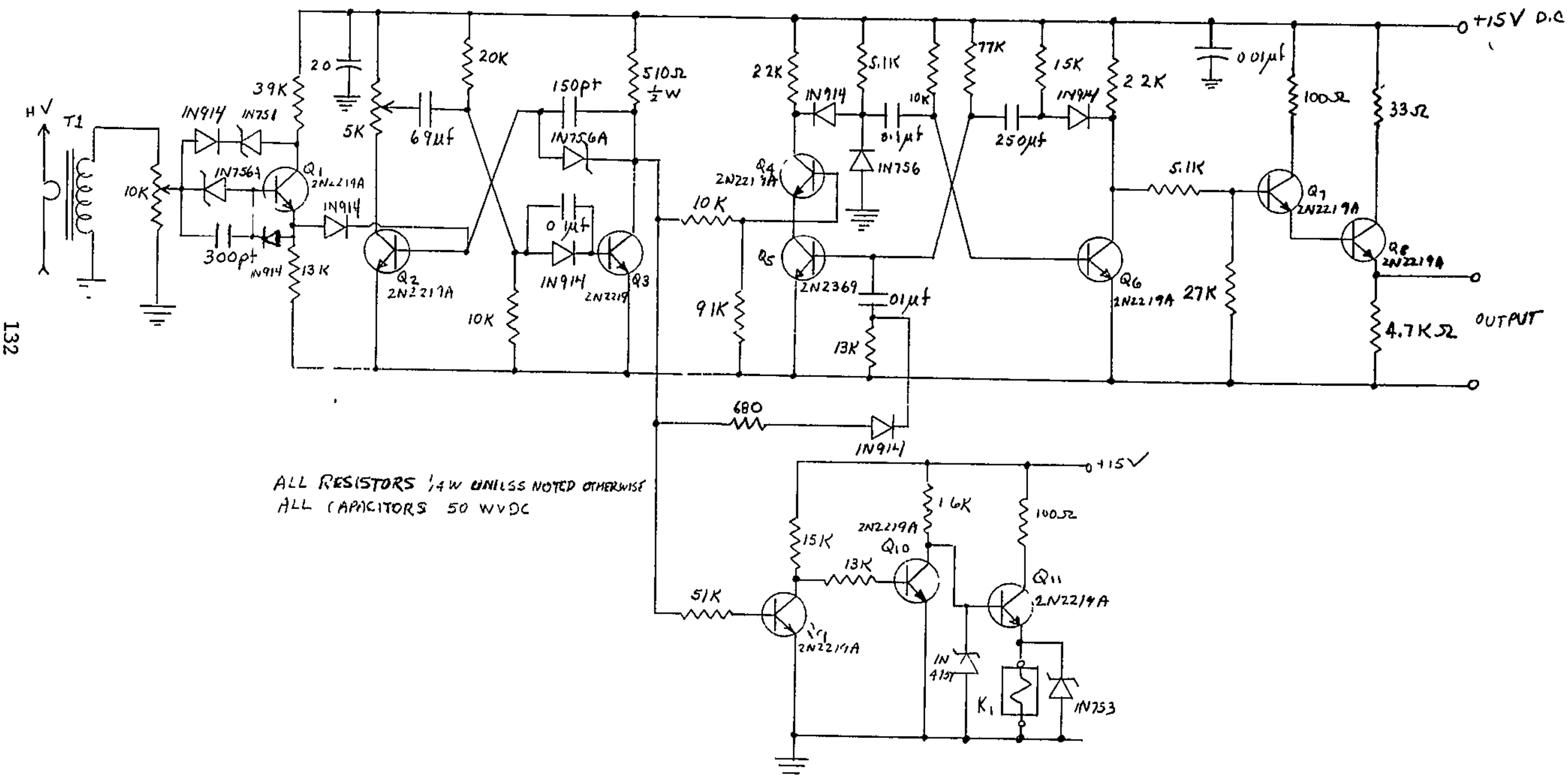


FIGURE 5-13. TRIGGER, LOGIC, AND CONTROL CIRCUITRY

Q_2 and Q_3. The pulse length of the latter is varied by changing the value of the 5 K pot in the collector of Q_2. Pulse lengths of up to 80 msec can be achieved. The output pulse is fed simultaneously to trigger an astable multivibrator and to a relay driver circuit (Q_9, Q_{10} and Q_{11}). The relay provides a disconnect signal for the prime power source while the free running multivibrator (Q_4, Q_5 and Q_6) and associated amplifier (Q_7 and Q_8) provide output pulses of 10 volt amplitude for the length of time the one-shot multivibrator is on. The pulse repetition rate is approximately 30 pps; up to 4 pulses are available depending on the one-shot multivibrator adjustment. The output pulses are fed to the TM-11 commercial trigger module which develops 30 KV pulses to fire the spark gap.

5.5.3 VSWR Trip Circuit

Protection of the transmitter output tubes against dangerously high VSWR's will be provided by a circuit which samples a portion of the reflected signal from a directional coupler, rectifies it, and compares it to a preset level. If the rectified signal exceeds this threshold a relay is actuated which in turn will remove power from the transmitter and thus protect the output tubes. The schematic of this circuit is shown in Figure 5-14.

5.5.4 Trigger Module

An EG&G TM 11 Trigger Module was purchased to provide the 30 kV pulses necessary to fire the GP12BV spark gap. The module consists of a DC power supply, pulse transformer and KN2 Krytron discharge tube which discharges a variable amplitude pulse into the pulse transformer to provide a firing pulse variable in amplitude from 15 to 30 kV. The module can be triggered from a front panel switch, a remote switch, or by 10 V pulses from a pulse generator.

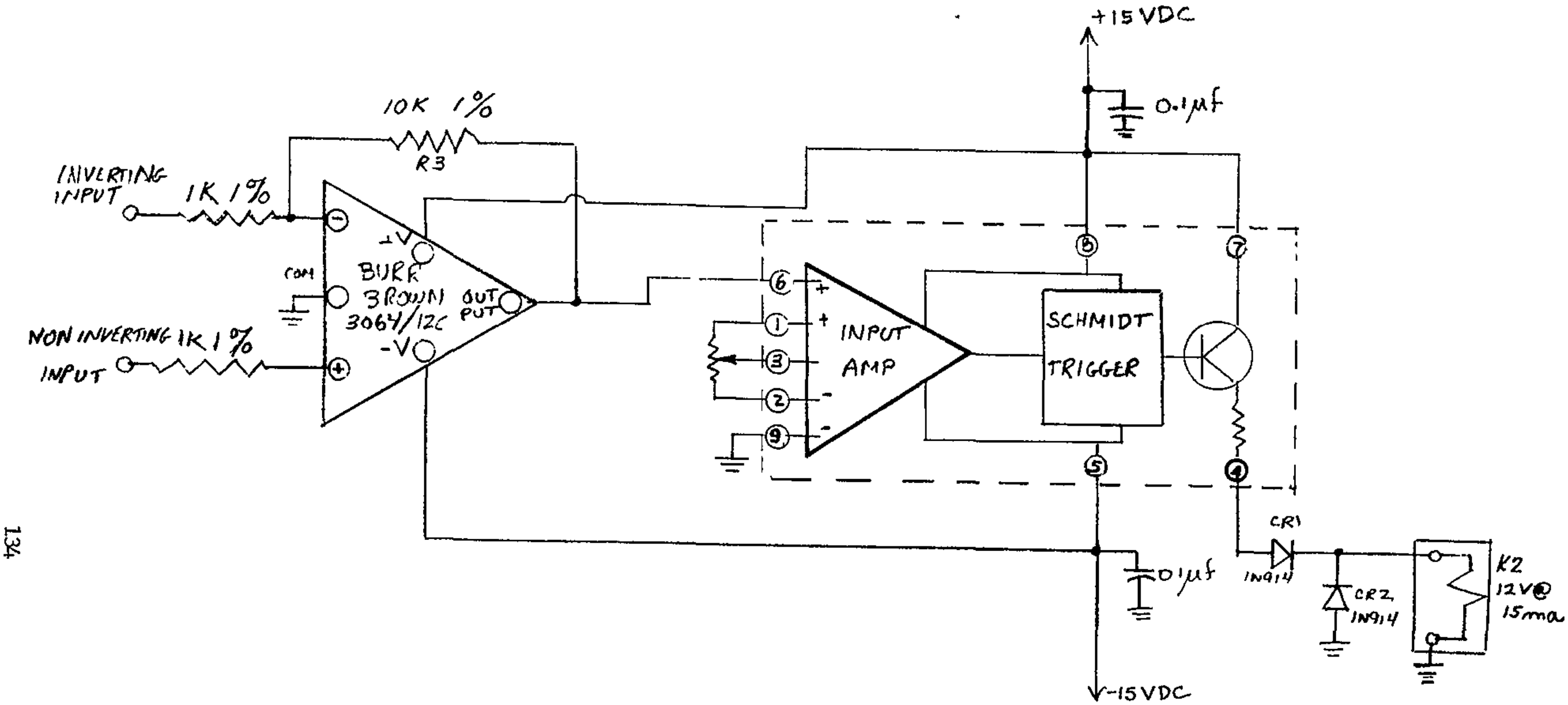


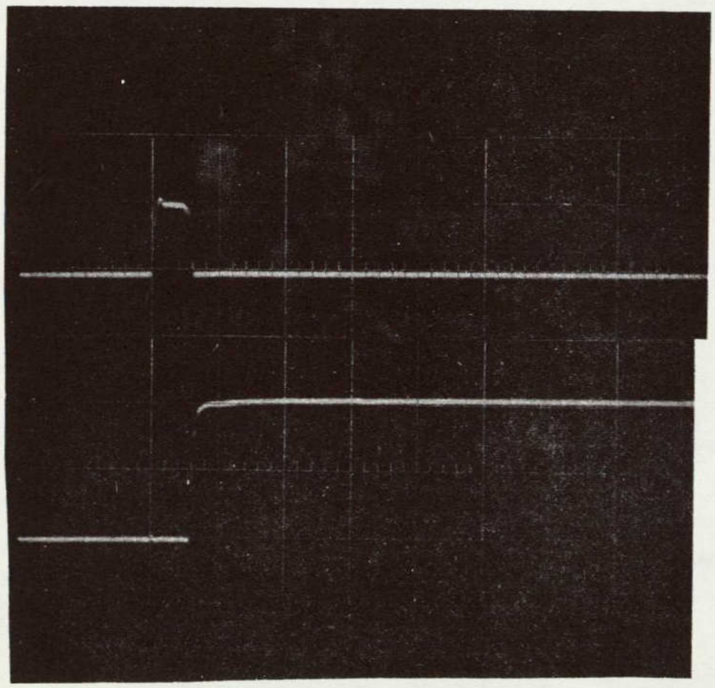
FIGURE 5-14. VSWR TRIP CIRCUIT

5.5.5 Operation

The crowbar unit is placed in operation by providing interconnections to power supply control circuits such that the closure of a normally open pair of relay contacts will remove high voltage. High voltage connections are made through special BNC style connectors on the chassis rear surface. An indication of the speed of action and degree of protection provided by the crowbar was the aluminum foil, test, shown in Figure 3-18. The total delay time between the fault current pulse and the first output 30 kV trigger pulse of the TM 11 has been measured to be 0.6 μsec, and is shown in Figure 5-15. The delay from the input pulse until the relay closed was about 3 microseconds.

5.5.6 Driver Crowbar Design

A schematic diagram of the crowbar used in the 1 kV power supply for the visual driver amplifier stage is in Figure 5-16. It employs a KN2 Krytron tube as the crowbar element and a TR149 trigger transformer to fire the tube. The crowbar fires with very little delay, successfully passing the 0.5 mil aluminum foil puncture test.



VERT = 5 Volt/cm

HORIZ = 1 μsec/cm

Top trace is input pulse to trigger circuitry.

Bottom trace is front of firing pulse to TM 11 module.

Total delay shown = 0.6 μsec

Figure 5-15. Measured Trigger Pulse Delay

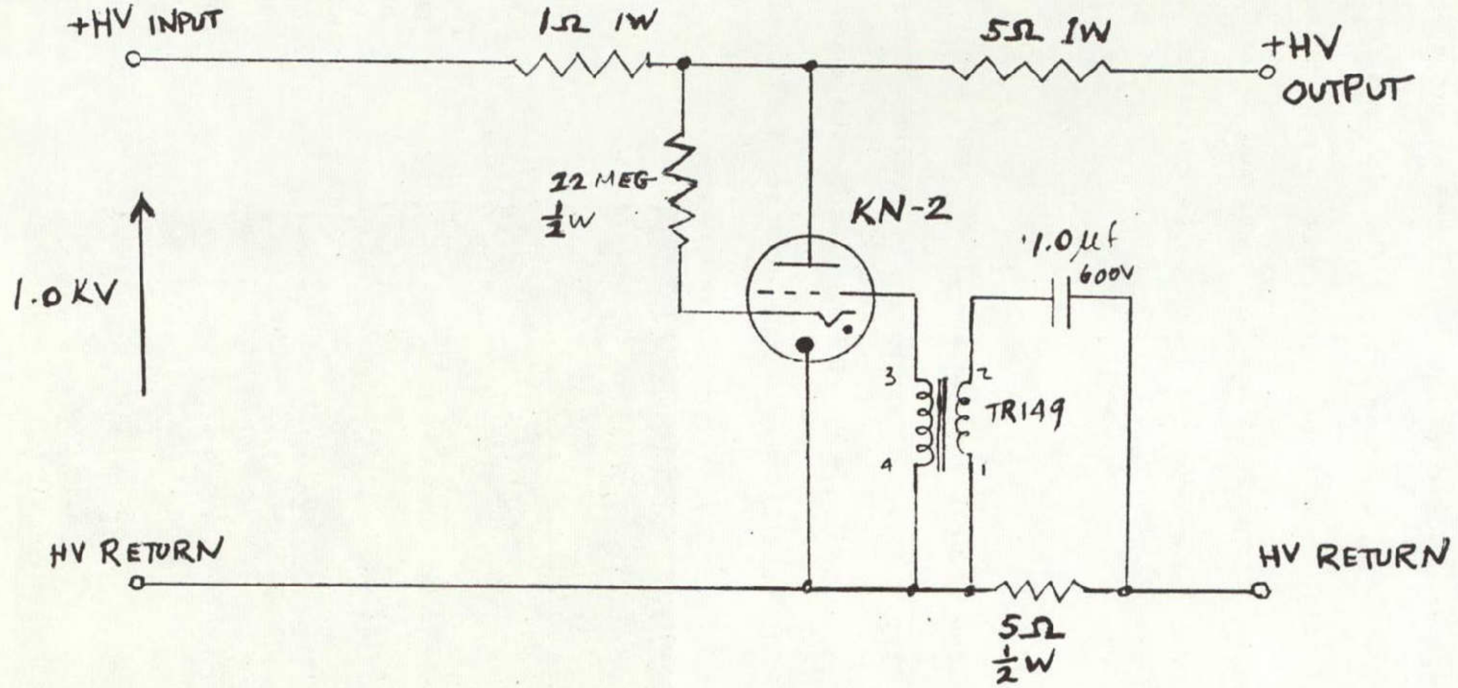


FIGURE 5-16. DRIVER CIRCUIT CROWBAR

5.6 CONTROLLED CARRIER CIRCUIT DESIGN

5.6.1 Requirements

The basic requirements for the controlled carrier circuit were in Section 2.3.6; supplemental requirements include the following:

RF Gain Control Element

Insertion Loss	1.0 dB or less (minimum attenuation) to 6.0 dB (maximum attenuation)
Signal Transfer Amplitude Linearity	$\pm$ 0.25 dB over the video signal range of +0, -20 dB (referred to sync peak) at any point of the 6.0 dB variable loss range.
Phase Linearity	$\pm 3^{o}$ over the video signal range of +0, -20 dB (referred to sync peak) at any point of the 6.0 dB variable loss range
RF Connectors	Type N

Power Demand Sampler

Sampler Element	Sampling resistor in B- circuit; followed by adjustable threshold circuit.
Sampler Output	A dc voltage proportional to instantaneous power demand of rf amplifier.
Sampler Output Voltages	Typically 1.0 to 5.0 volts average level at the control point

Control Unit

Input Voltage	From Power Demand Sampler
Output	As required to drive the RF Gain Control Element over the specified range
Power Demand Regulation	$\pm$ 2% maximum deviation between the "average gray" clamp level and the "all black" video signal
Average Gray Clamp	A selected average video level in the composite TV signal, gain must be constant for signals below the clamp level.
Control Time Constant	Variable, 0.6 to 20 milliseconds.

Drift in Gain	$\pm$ 0.1 dB over a 4 hour period for a normal air conditioned room environment ($\pm$ 3°C)
Test Points	Monitoring points for all significant currents and voltage
<u>RF Control Element</u>	Diodes packaged in an rf shielded enclosure.
<u>Personnel Safety</u>	
High Voltage	All terminals more than 24 vrms above ground will be adequately insulated or shielded
RF Radiation	Maintained below 10 milliwatts per square centimeter at all points accessible to personnel.
Hot Spot temperature	The outside surfaces of circuitry operating above 100°C will be adequately shielded to prevent personnel contact.

5.6.2 <u>Circuit Design</u>

The circuit of Figure 5-17 is divided into four components; the RF Drive Attenuator, the Attenuator Control Circuit, the Power Sampling Circuit, and the HV Power Supply.

The Power Sampling is achieved by monitoring the final amplifier plate current. A voltage is developed across a 2 ohm resistor (R1) located in the high voltage power supply return. Normally, the average dc plate current will be 1.5 amperes ; therefore, the nominal monitoring voltage will be 3 volts. Voltage transients that appear across this resistor will be filtered out.

The Attenuator Control Circuitry amplifies and activiely filters the sampled voltage of the power sampling circuit and drives the RF attenuator. The Sampling Circuit input network composed of C1, Z1, D1, D2, R2, and R3 serves as a low pass filter with a break point of 310 Hz. The network also protects the front end of the IC amplifier (IC1 in Figure 5-17) from any transients that may appear. The control threshold level is set by R12, R13, and R14. The time constant of the feedback network is varied by R5 and by switching C2; six ranges cover a 0.24 to 22 msec. span. Provisions are included for adding an external capacitor to the filter network. The three potentiometers are ganged to keep the gain and threshold constant while varying the time constant.

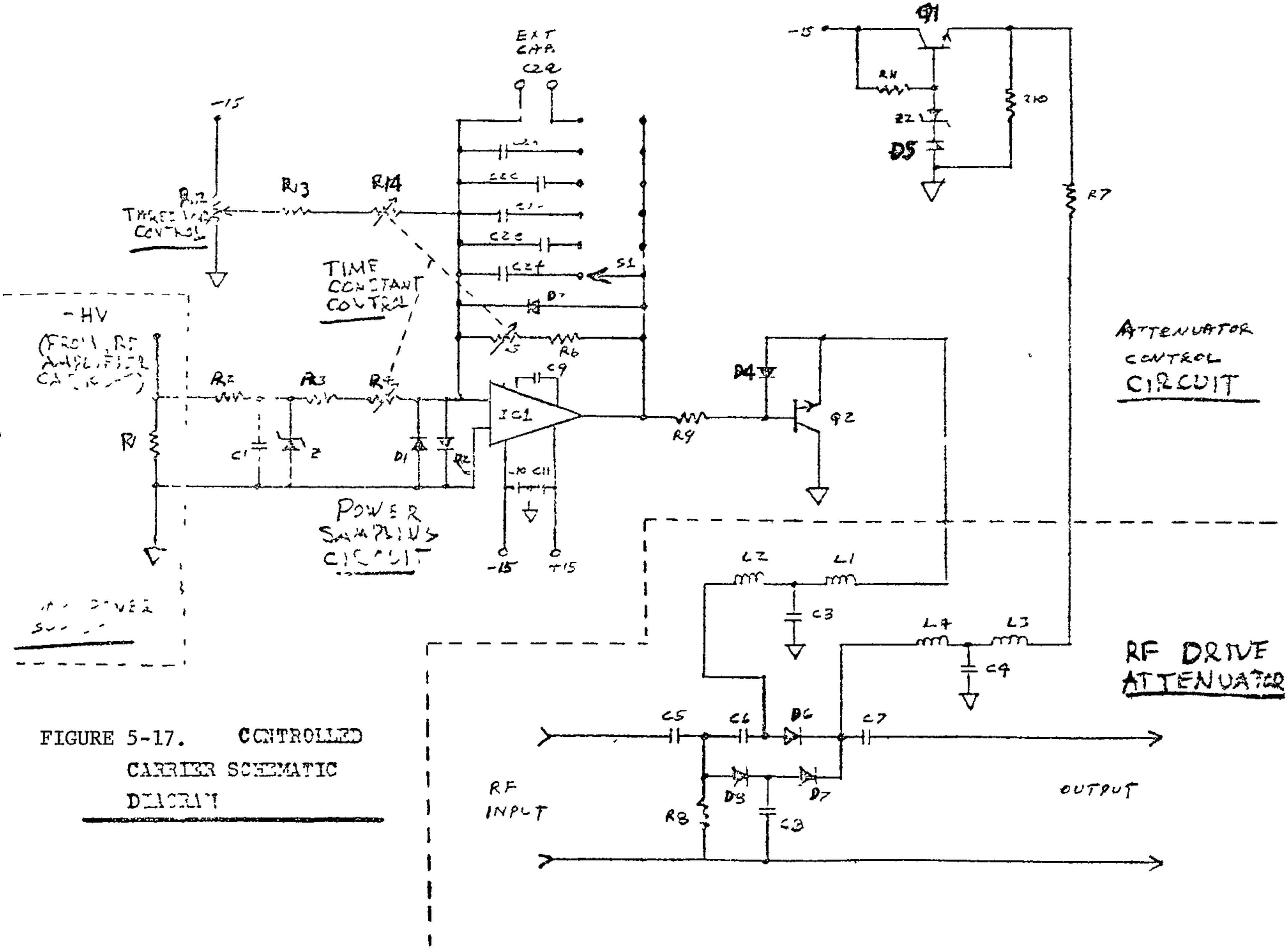


FIGURE 5-17. CONTROLLED CARRIER SCHEMATIC DIAGRAM

Diode D3 clamps the output of the amplifier at + 0.7 maximum volts, thus limiting its dissipation during periods of minimum attenuation. Transistor Q2 serves as an emitter follower to handle the required attenuator drive current.

A compensation regulated -10 volts is supplied by the series regulator Q1, Z2, D5, R10 and R11. Diode D5 compensates for the V_{be} due to temperature. The RF Drive Attenuator uses three PIN diodes in a pi configuration, biased in the proper ratios to keep the input/output impedance constant at 50 ohms over the usable range of 0.5 to 6 dB. In the full-on state, the emitter of Q2 is at approximately zero volts, and a 50 ma bias current flows through the series element D6 while the shunt elements D7 and D8 are reverse biased. As high attenuation is demanded, the emitter of Q2 goes more negative, reducing the current through the series diode D6 and increasing the current through the shunt diodes, D7 and D8. R7 and R8 are chosen to provide the proper bias ratio for constant impedance.

The two filters, L1, L2, and C3, and L3, L4, and C4 are low pass isolation filters with break points of approximately 10 MHz. Capacitors C5, C6, C7 and C8 are dc blocking capacitors with an impedance less than 0.1 ohm at 800 MHz.

The circuit is capable of providing the required performance, and is the circuit to be fabricated for tests to be conducted on the complete breadboard transmitter in the Phase B effort to follow.

5.6.3 Implementation

The general analysis of the circuit[16] shows no difficulties in the circuit approach. Voltages, currents, impedances, and required components are all within normal ranges. The parts required for the circuit of Figure 5-17 are:

R1	2 ohms, 25 watts, non-inductive	
R2	270	
R3	270	
R4*	500 per section	
R5*	50K per section	
R6	51K	
R7	180	1 watt
R8	62K	
R9	510	
R10	2K	
R11	330	
R12	2K	pot.
R13	100K	
R14*	100K	pot.

* Ganged - all linear taper

C1	.5 µf
C2a	external
C2b	.01 µf
C2c	.022 µf
C2d	.047 µf
C2e	.1 µf
C2f	.22 µf
C3	.002 µf
C4	.002 µf
C5	.002 µf
C6	.002 µf
C7	.002 µf
C8	.002 µf
C9	30 pf
C10	.01 µf
C11	.01 µf

Q1 and Q2	2N1711	
D1 to D5	1N914	
D6 to D8	UM6006	PIN
IC1	LM101A	

L1 to L4	10 µh

5.7 HIGH POWER RF COMPONENT ENVIRONMENTAL TEST PLAN

5.7.1 Approach to Tests

The Scope of Work for this contract requires the testing of several UHF RF components in a vacuum environment. In descending order of preference, several representative test items are:

1.	Uniform 2-1/8 inch coaxial line	3-1/8 inch, 50 ohm
2.	Uniform Waveguide line	half-height WR975
3.	Coaxial step, 3-1/8 inch, Length = 14 inches	a) 1 mm gap b) 2 mm gap c) Contaminated Surface (Oil Film) d) Plasma Torch Spray Materials
4.	Waveguide Step, half height WR975 Length = 20 inches	a) 1 mm gap b) 2 mm gap c) Contaminated Surface (Oil Film) d) Plasma Torch-Spray Materials
5.	Color Subcarrier Image Filter-Waveguide	WR975 half-height, 10" x 14"
6.	3 dB Hybrid, Dual WR975 Waveguide	Length - 24 inches

If time permits, two other components of particular interest are:

7.	Waffle Iron Section	10" x 20"
8.	Waveguide Slot	10" x 12"

The two stepped sections (see Figures 3-23 (b) and (d)) represent segments of reactive harmonic filters, which may be used in a high power system for coaxial and waveguide transmission. They also represent lower impedance coaxial, rectangular waveguide, and ridged waveguide lines which are a possible approach to multipactor prevention. (See Appendix A for low impedance line analysis.) These two items with step sections are matched by quarter-wavelength impedance transformers. Each step section component will initially be fabricated with a gap separation of one millimeter (.039") to minimize probability of multipacting; additional subsequent units of wider gap spacings will also be fabricated. The waveguide stepped section is shown in Figure 5-18.

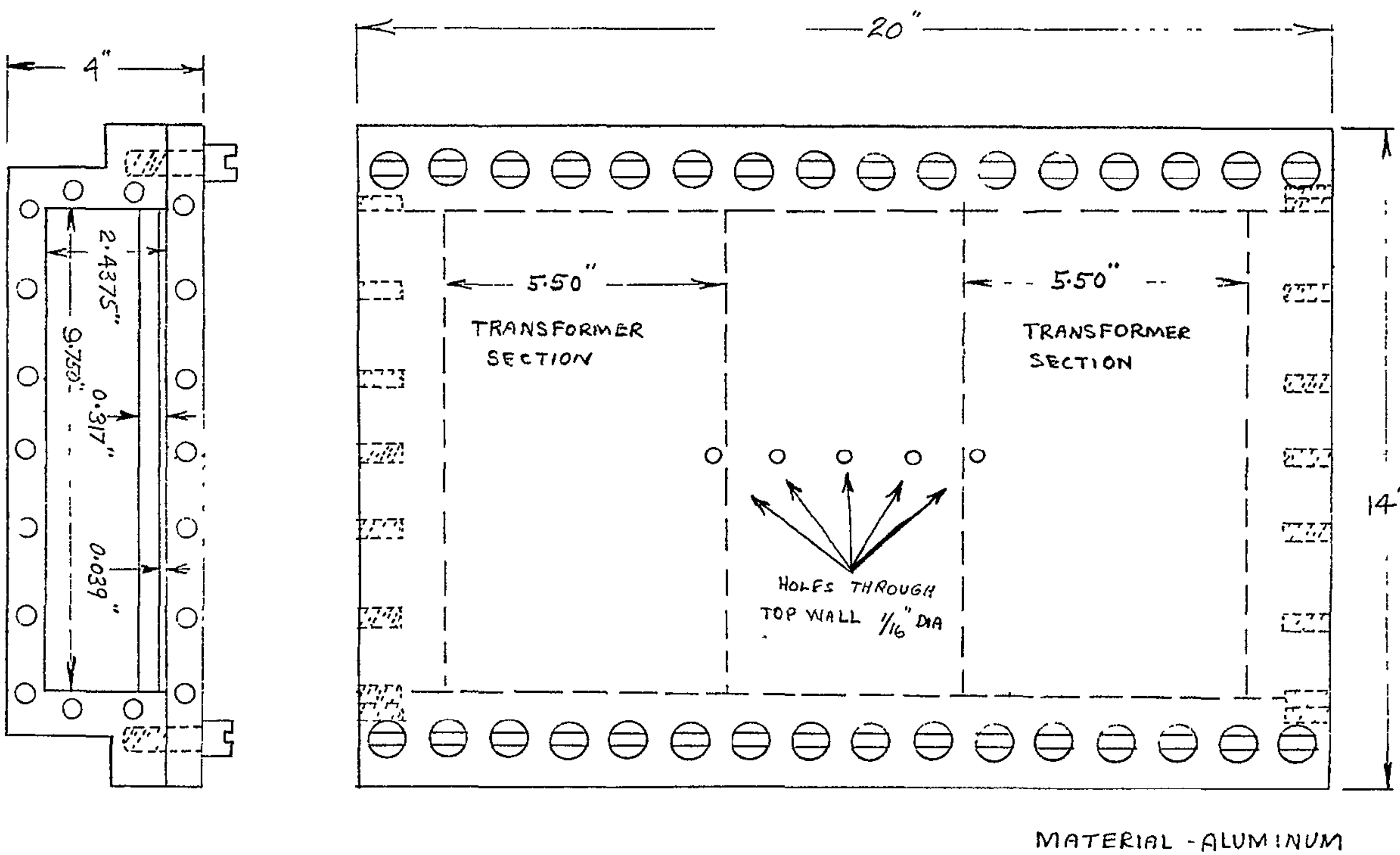


FIGURE 5-18. STEPPED WAVEGUIDE SECTION

The waveguide hybrid, Item 5 on the list of components, will be operated with short circuit terminations on the output ports to simulate a balanced diplexer situation. Some multipactor monitoring-point holes would be located in the body of the hybrid, and venting holes will be required to avoid outgassing buildup. The GE hybrid will be used for this test.

The color subcarrier image filter will be removed from the waveguide assembly for testing in the vacuum.

5.7.2 Test Setup

The experimental test setup for component multipactor breakdown is shown in Figure 5-19. A 2.5 kW, 800 MHz CW transmitter feeds into a heliax coaxial transmission line to the vacuum chamber. At the vacuum chamber, rigid 3-1/8 inch coaxial line is employed. Pressure isolation of the test component apparatus within the chamber is accomplished by utilizing 3-1/8 inch coaxial line gas barriers and special (Vitron-A) O-ring seals. Directional couplers facilitate coupling for power monitoring, incident and reflected power levels, and pulse monitoring. Thermocouples are placed liberally at selected locations for temperature monitoring. A conventional ionization gauge tube and metering equipment is employed for pressure measurement at levels of 10^{-6} mm Hg. (This device is discussed in Reference 20.)

Multipactor discharge indicators to be employed are the "Faraday Cup" and visual observation approaches. The Faraday Cup type of measurement will use a positive biased collector brass plate placed over small holes through the coax outer conductor (or waveguide broadwall) of the test component where multipacting is anticipated Some of the moving electrons in the multipactor discharge will pass through the holes where they are collected on the biased plate(s). The basic circuitry involving implementation of this device is shown in Figure 5-20.

* NOTE - USE ADAPTERS AS NECESSARY
IN THESE LOCATIONS

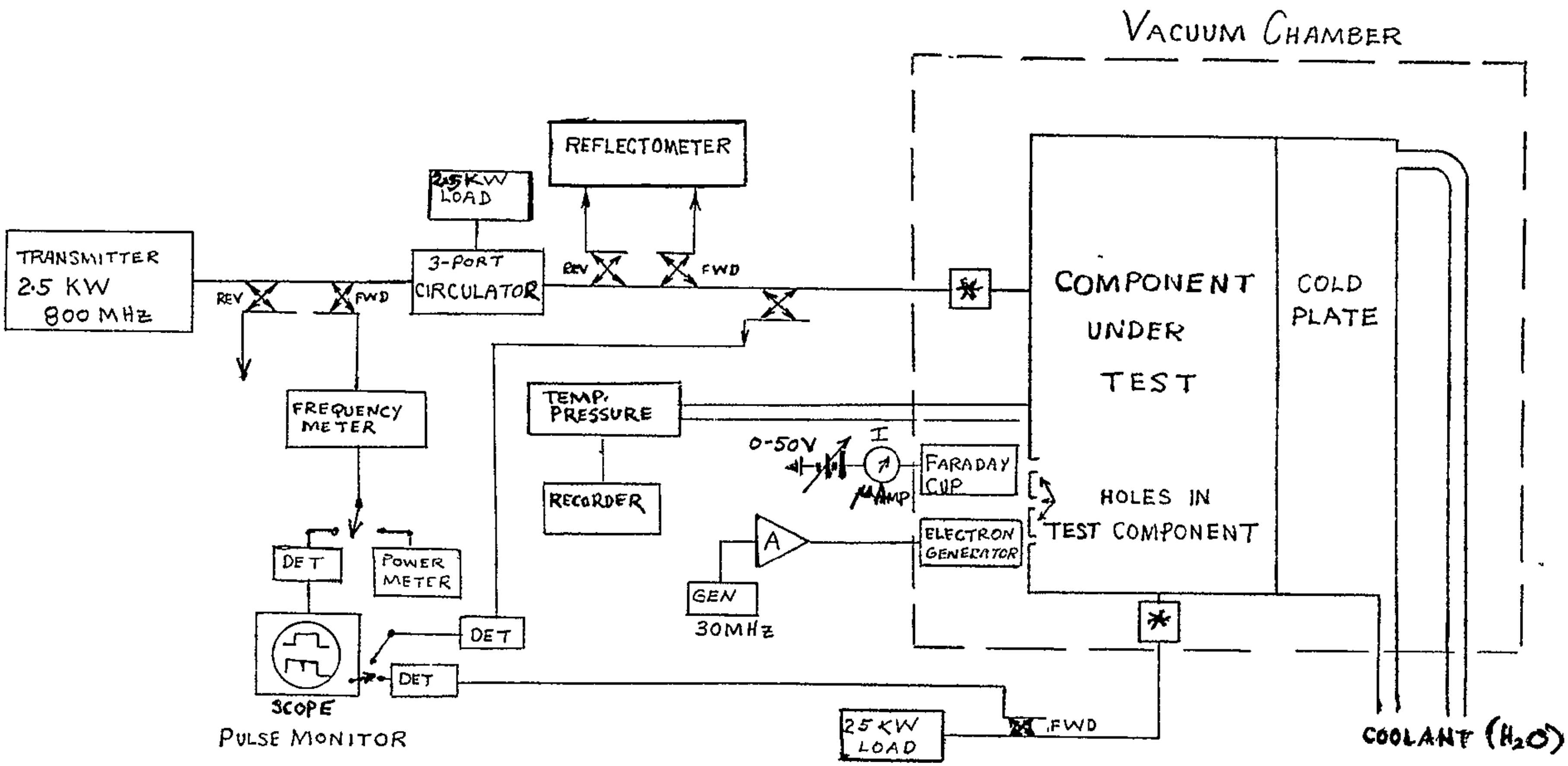


FIGURE 5-19. EXPERIMENTAL TEST SETUP FOR HIGH POWER MULTIPCATING TESTS

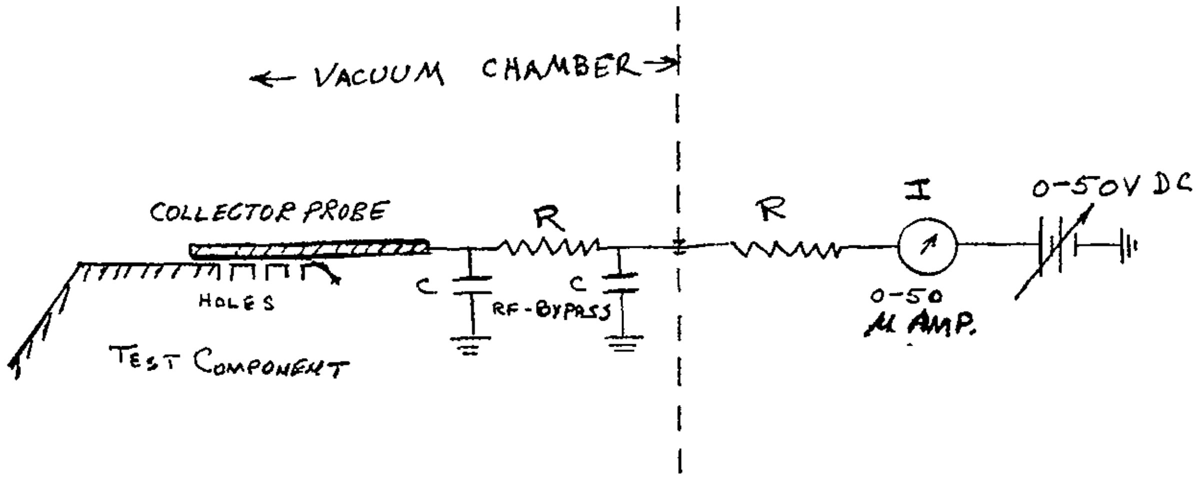


FIGURE 5-20. FARADAY CUP - SCHEMATIC ARRANGEMENT

The vacuum chamber selected for these tests has working dimensions of a 30 inch diameter with 40 inch length, with a vacuum level capability of 10^{-6} torr. Access chamber ports will accommodate 3-1/8 inch diameter coaxial line. Special flanges will be brazed on the rigid coaxial line outer conductor exterior and attached to the existent vacuum chamber flange. Conventional O-rings will be utilized on the exterior flange. A special O-ring will be used with the gas barrier for isolating the interior of the coaxial line. Optical viewing ports on the end of the chamber facilitate visual monitoring of the device under test.

To enhance the probability of multipacting, excess free electrons will be generated with an auxiliary multipacting gap located adjacent to the test item, as indicated in Figure 5-21. A generator and amplifier operating at about 30 MHz will feed the probe through a resonant tank circuit. The resonant tank circuit is comprised of a variable L-C network with a tapped output inductor to provide input impedance matching by selection of the proper turns ratio.

Component cooling in the vacuum chamber will be accomplished with water passage through copper tubing attached physically to the test piece or to an attached cold plate.

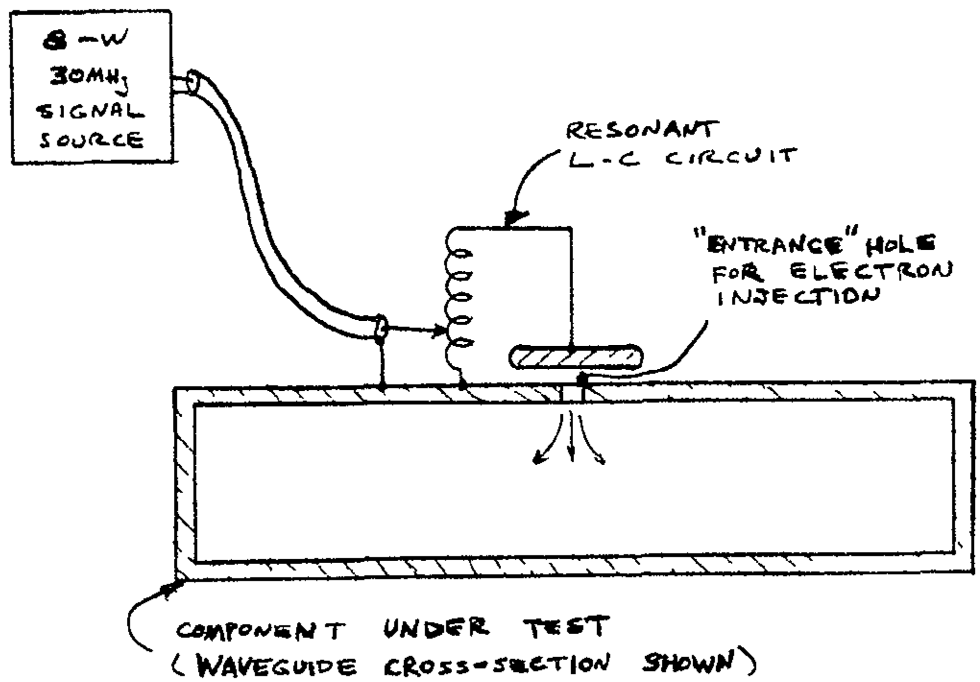


FIGURE 5-21. MULTIPACTOR TYPE ELECTRON INJECTOR

5.7.3 Test Procedure

Certain preliminary procedures will be established prior to actual power test for multipactor or ionization. Initially component surfaces will be abrasively cleaned and baked out if necessary to minimize out-gassing which may stimulate arc discharges. At the same time sufficient venting of each test component will be provided during the test to facilitate gas escape. If necessary, heater tape wrapped around the test component will expedite outgassing to achieve a high vacuum in a short period, although the tape must not be a heavy outgasser. Several holes will also be drilled through the outer wall to accommodate outgassing.

Once the desired vacuum pressures have been obtained, the coaxial step will be tested. Several types of data may be obtained for input power versus gap spacing. Variations of this data will then be obtained for various dc voltage bias levels (outer conductor relative to center conductor) on the coaxial conductors or on an auxiliary conductor located within the coaxial line. Additional test data on this (and other) components (as test results and schedule permit) will evaluate the use of flame-sprayed low secondary yield materials. Techniques employed in this approach are described in detail in Reference 22. Tungsten carbide will be used in most or all of these tests since it appears to be highly effective and has the least loss of the effective materials tested. RF loss changes as well as multipactor suppression will be evaluated.

Power will be transmitted through each test component except the hybrid. The dual-guide hybrid will have a mesh or perforated material shorting plate over one of the dual waveguide ends. The coupling and phasing characteristics of this hybrid provide combining of the reflected power out of the adjacent output port, so that no power is reflected back toward the input port. Further discussion on description of the hybrid is detailed in Reference 21.

When all preliminary conditions of pressure and outgassing are met, the detailed test data with applied power will be obtained. Since several parameters require monitoring, recorders will be employed. Conventional recording equipment at the vacuum chamber records temperature and pressure.

5.8 TRANSMITTER SYSTEM TEST PLAN - TASK 8

5.8.1 Test Requirements

The purpose of the transmitter system tests is to provide a measured basline of operating parameters, giving the operational capabilities of the equipment. This includes both electrical and thermal data, and provides the data required for a general-purpose high-power space transmitter. The initial operational tests are followed by AM-TV tests to indicate the performance capability as a TV transmitter; this is followed by the Controlled Carrier tests to demonstrate capability for achieving a high level of AM-TV performance with a restricted capacity power supply.

The tests will comprise the following:

1. Power, efficiency, gain and thermal (performance tests)
2. TV Picture Quality
3. Harmonic Output
4. Controlled Carrier Operation
5. Power Supply and Transient Effects
6. Upper and Lower Sideband Attenuation (Visual channel)
7. Aural Channel Tests

A list of the test equipment required for these tests is in Appendix B. A test exciter has been assembled, interconnecting items from the list of test equipment as was shown in Figure 3-24. This will provide test signals to both the visual and aural channels at 5 watt levels for each. The visual signal generator will provide the test signal formats required to ascertain the performance in accordanct with the standards of EIA-RS 240.

5.8.2 Performance Tests

5.8.2-1 Purpose of Tests

This test series is to determine the power capabilities of the transmitter, amplifier efficiencies and gains, and heat dissipation for each portion of the equipment under various operating conditions. Tests will be made at the carrier frequency, and with

necessary modulations to demonstrate operation. Unmodulated operation will be used for lower signal levels, and pulsed operation where high signal levels are involved, such as making sync peak measurements where continuous unmodulated signals would exceed tube and power supply ratings.

5.8.2-2 Description of Test

The equipment setup for the test is shown in Figure 5-22. The transmitter is temporarily modified by inserting a directional coupler between the driver and the final amplifier for the purpose of measuring transmitter stage gains. During the test all input voltages, currents, power levels, coolant temperatures and coolant flow rates are recorded.

The parameters are measured as the picture content to the transmitter is varied. Thus, the input power requirements, output power, stage gains, efficiency, and means of heat dissipation are established for each portion of the transmitter under various operating conditions.

5.8.2-3 Test Procedures

The tests will be performed starting with a white picture and increasing the gray level until the CW rating of the equipment is reached. At this point, the testing will proceed in a pulsed mode until the peak sync level is reached. This is required because the transmitter is designed to handle an average picture content of about 1.6 kW, and it cannot accept the sync pulse (5 kW) or an all black picture (2.76 kW) on a continuous basis. Therefore, the duty cycle is reduced under pulse test conditions. In addition, when operating in a pulsed mode, the final amplifier will have a small idling current during the "off" portion of the cycle. This portion of power must be deducted from total amount to compute the true plate efficiency.

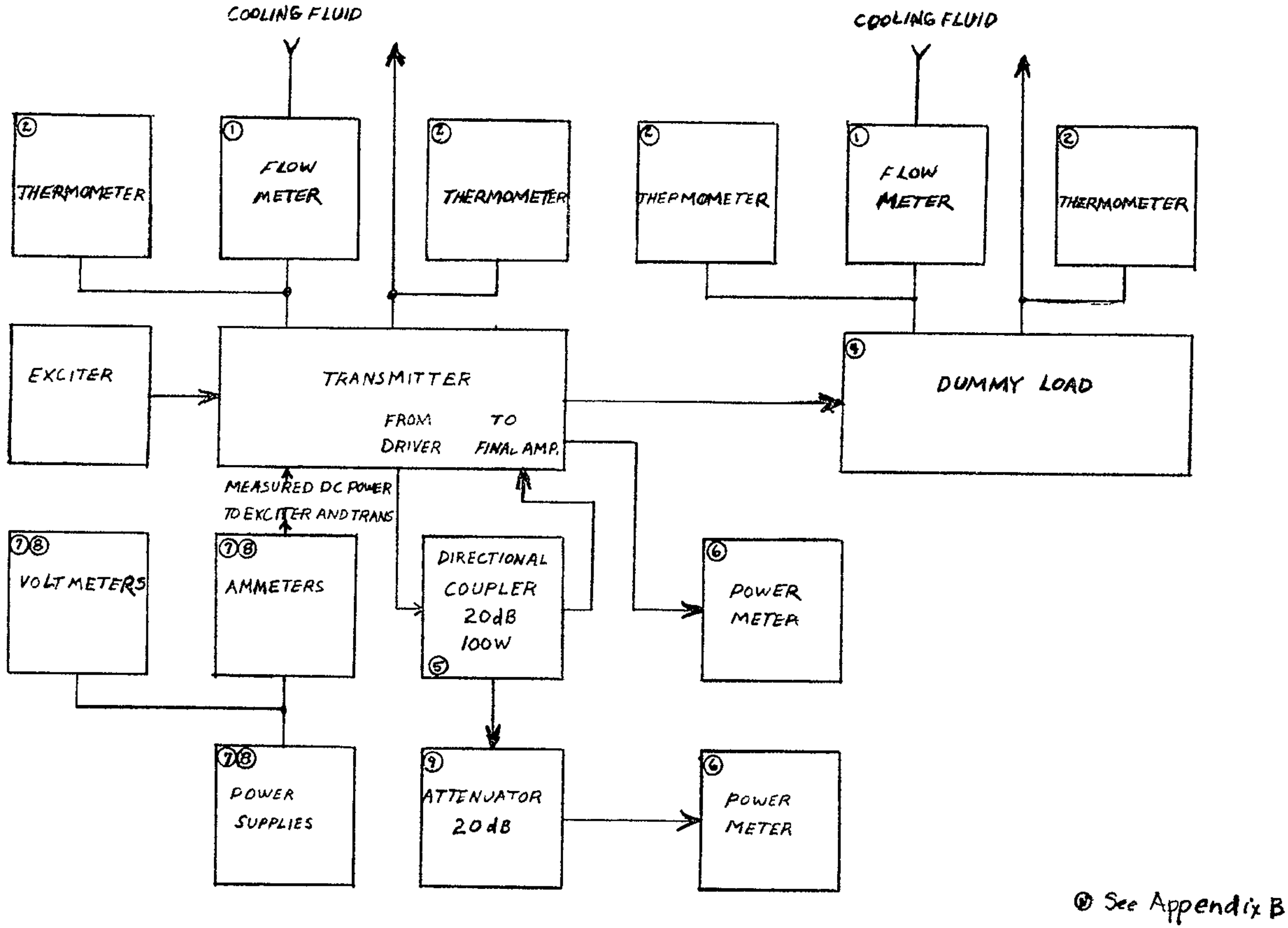


FIGURE 5-22. TEST EQUIPMENT FOR OPERATING PARAMETERS MEASUREMENTS

5.8.3 TV Picture Quality Tests

TV picture quality tests are based on the EIA Standard[3] and will cover six performance areas. These are described individually below.

5.8.3-1 Frequency Response Tests

This test is to establish the overall video amplitude versus frequency response to verify that it is in accordance with EIA standard RS-240. Figure 5-23 shows the major response requirements.

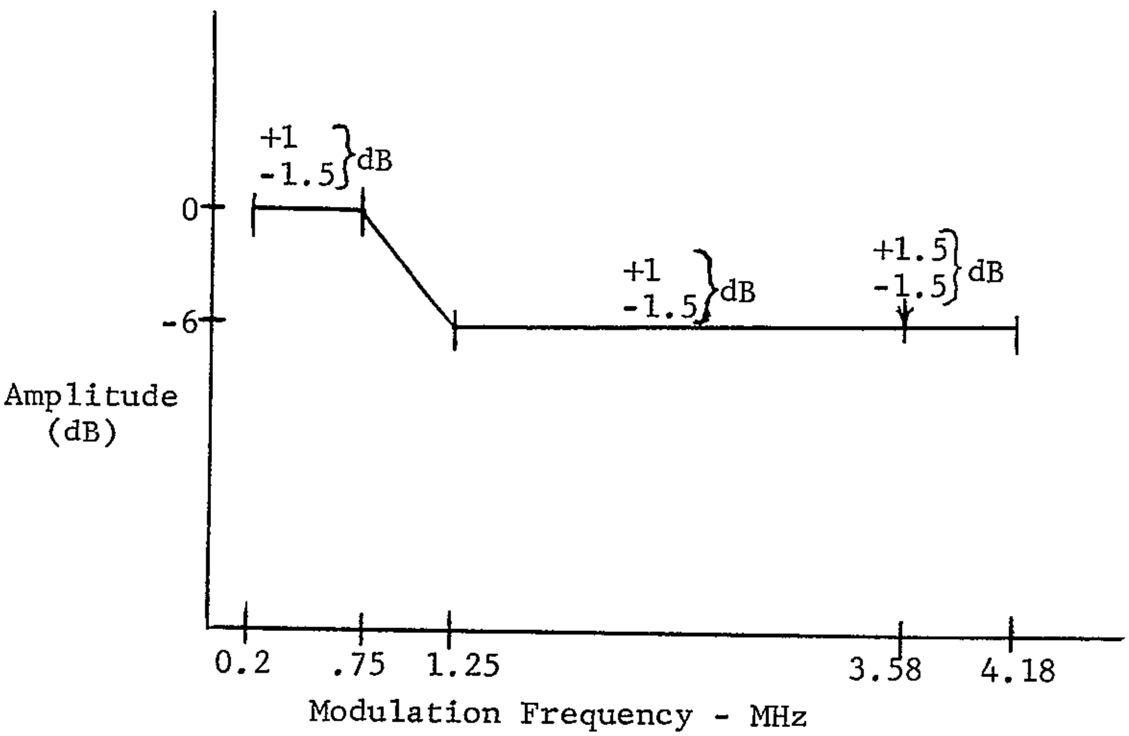
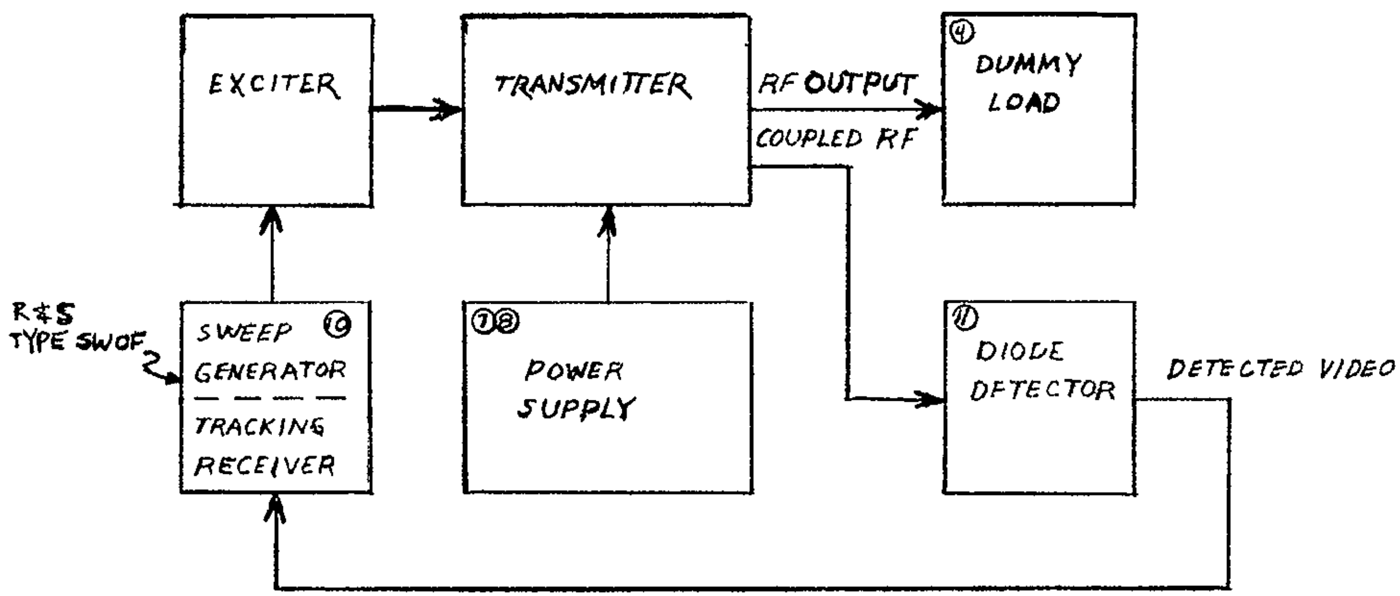


Figure 5-23. EIA Frequency Response and Limits

The equipment setup for the test is shown in Figure 5-24. An exciter tracking-receiver generates a swept video response signal. The built-in receiver portion of the test equipment, a narrow band tracking receiver synchronixed with the exciter displays the amplitude versus frequency characteristic of the transmitter under test. The diode detector is attached to the directional coupler forward power monitor terminal



N See Appendix B

FIGURE 5-24. TEST EQUIPMENT SETUP FOR FREQUENCY RESPONSE TEST

to measure the transmitter output response. The amplitude versus frequency response is photographically recorded from the oscilloscope.

5.8.3-2 Linearity Test

This test is to determine the low frequency (200 kHz) output amplitude versus input amplitude for the transmitter. The non-linearity shall not exceed 1.5 dB (referenced to the amplitude of the greatest step) at the 10, 50, and 90% APL (average picture level) when using a stairstep signal having ten steps of equal amplitude from the reference white to pedestal level region.

The equipment setup for the linearity test is shown in Figure 5-25. The exciter provides an AM signal to the transmitter. The signal is modulated by synchronizing pulses and a standard five or ten step video signal. The transmitter RF output is detected and fed to an oscilloscope with a type "W" preamplifier and response is recorded photographically.

5.8.3-3 Differential Gain Test

This test is to measure the differential gain of a 3.58 MHz signal as the average picture level (APL) is varied from 10 to 50 to 90%. This test requires that a 3.58 MHz sine wave super-imposed on a low frequency composite signal shall not vary more than 1.5 db for 10, 50, and 90% APL (average picture levels) signals, with the maximum gain region used as the reference.

A composite modulated signal consisting of synchronizing pulses, ten step picture level, and 3.58 MHz subcarrier is fed to the transmitter as shown in Figure 5-26. The output is video detected and the 3.58 MHz signal selected by means of a filter in the test equipment. This signal is displayed on a vectorscope (or alternately, a

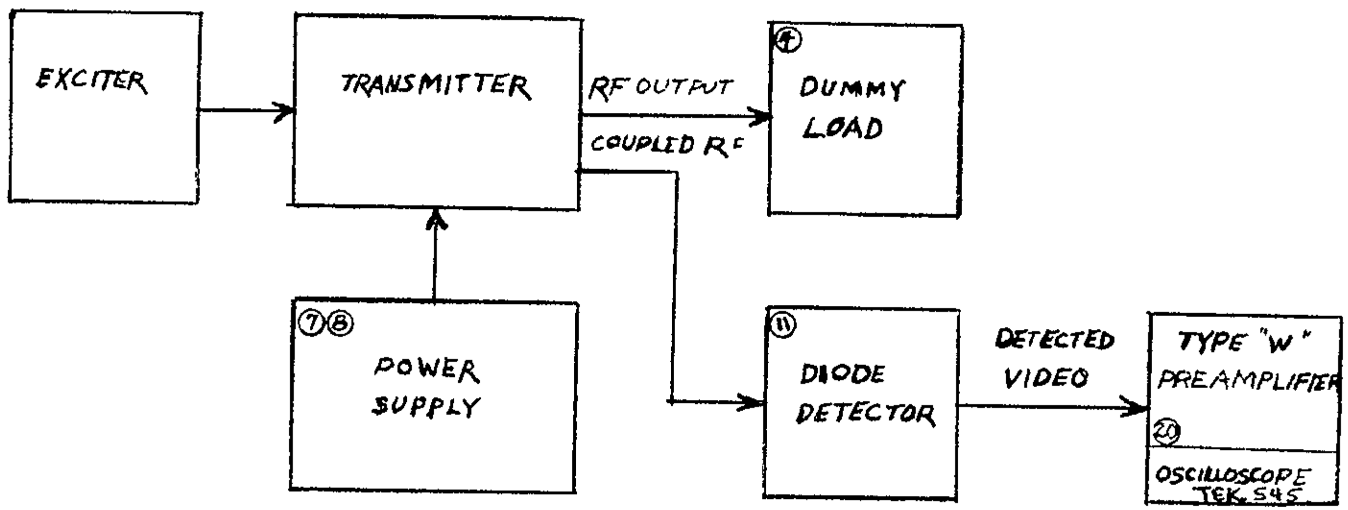


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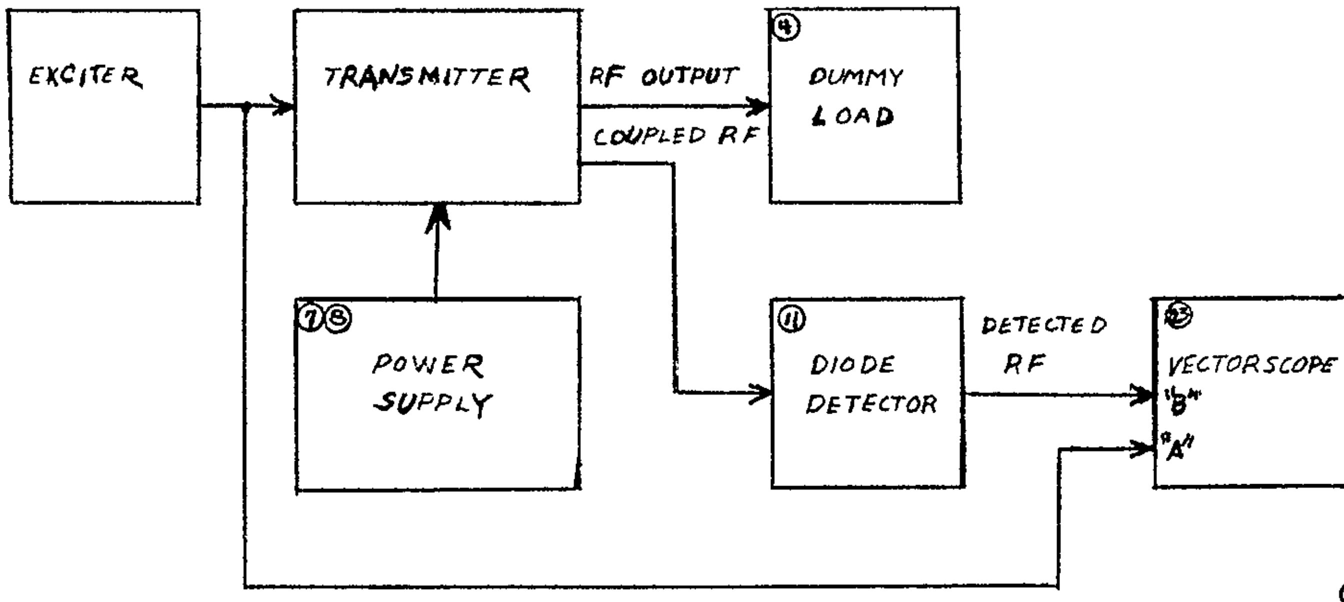
FIGURE 5-25. TEST EQUIPMENT SETUP FOR LINEARITY TEST



N See Appendix B

FIGURE 5-26. TEST EQUIPMENT SETUP FOR DIFFERENTIAL GAIN AND PHASE MEASUREMENTS

waveform monitor) and examined for gain variations.

5.8.3-4 Differential Phase Test

This test is to measure the differential phase of a 3.58 MHz signal as the average picture level (APL) is varied from 10 to 50% to 90%. The test will verify that the differential phase is less than $\pm$ 7 degrees at 3.58 MHz when using the burst region as reference. In addition, the total differential phase between any two brightness levels will not exceed 10 degrees.

In the test arrangement of Figure 5-26, the visual transmitter input terminal will be fed a composite signal consisting of synchronizing pulses and a low frequency signal with a superimposed 3.58 MHz sine wave signal having a peak to peak amplitude of 20% of the low frequency signal amplitude between blanking and reference white. This composite test signal will be sufficient to modulate the visual transmitter to reference white while maintaining rated blanking level and rated visual transmitter output power. The coupled RF output is video detected and the 3.58 MHz signal extracted by means of a filter in the vectorscope. The phase of each step is compared in phase to that in the burst region.

5.8.3-5 Envelope Delay

This test is to measure the envelope (group) delay versus frequency characteristic of the visual transmitter. The envelope delay is defined to be the first derivative of phase with respect to angular velocity. The standard is portrayed graphically in Figure 5-27.

The equipment and setup for the test is shown in Figure 5-28. A swept frequency generator is modulated by the envelope delay measuring unit (EDMU); this signal in turn modulates the visual exciter. The transmitter output is detected and then demodulated by the EDMU. The demodulated signal is then compared with the original signal for the actual envelope delay.

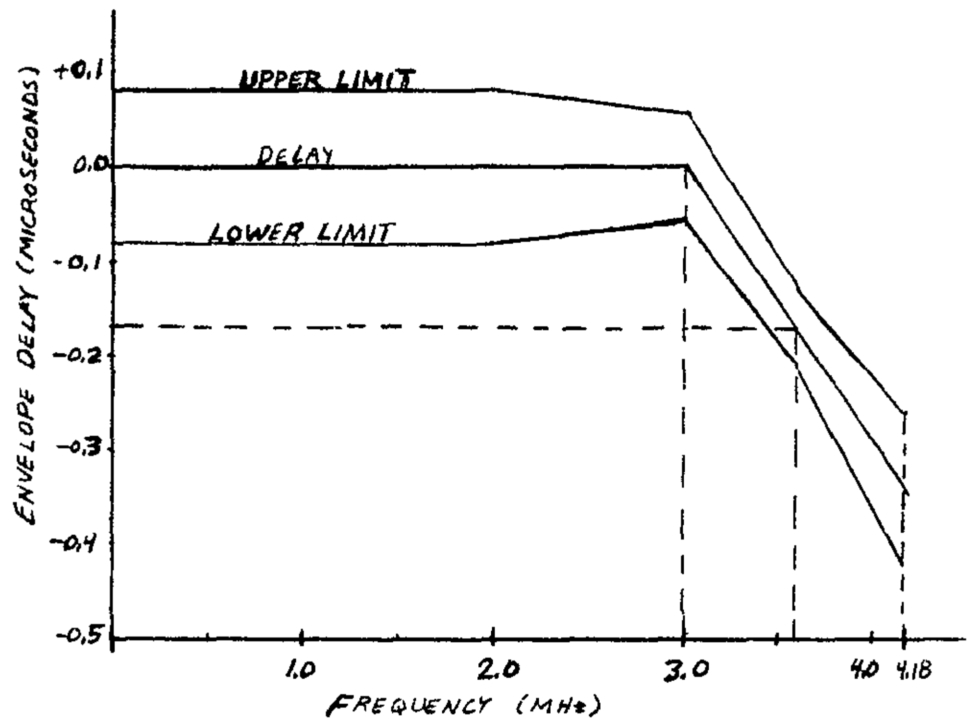


FIGURE 5-27. ENVELOPE DELAY FOR COLOR TV

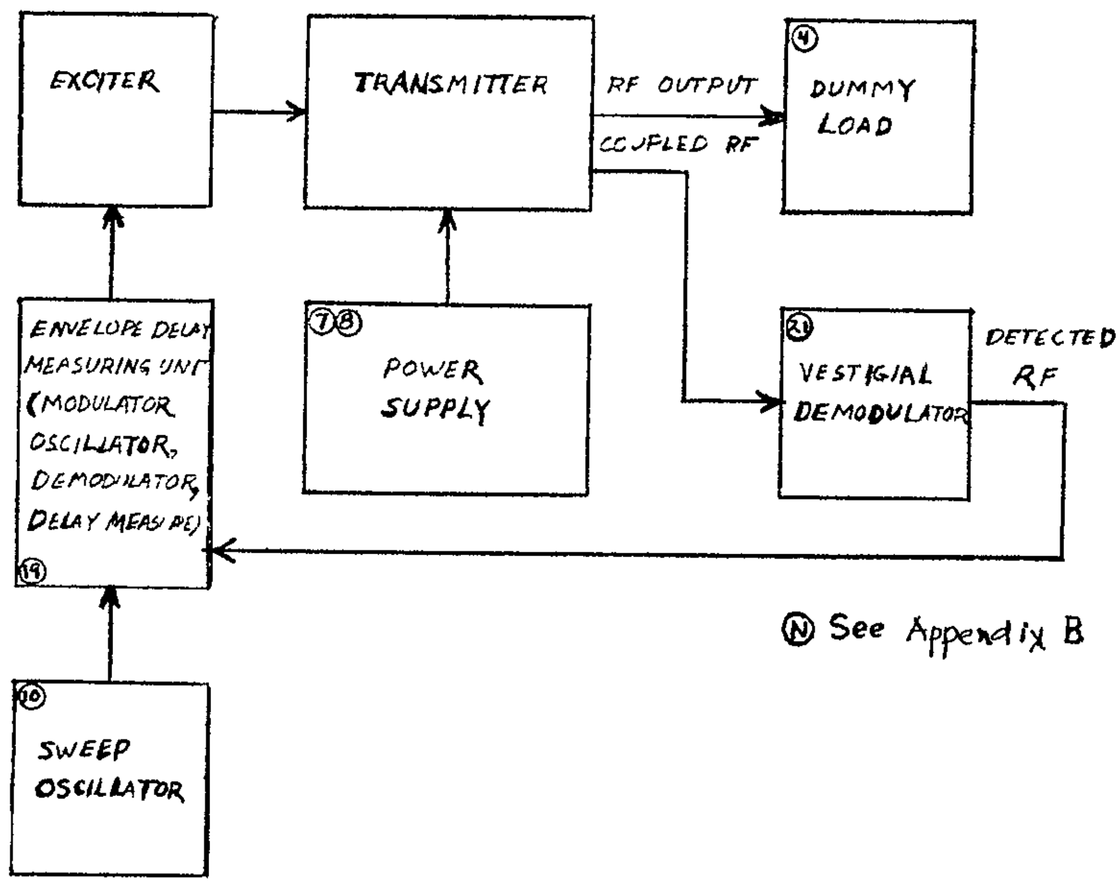


Figure 5-28. Test Equipment Setup for Envelope Delay Measurement

5.8.3-6 Hum and Noise

This test is to measure the hum and noise modulation in the amplitude of the RF output that is not produced by the video modulation signal. The hum and noise level within a band of 30-15,000 Hertz should be at least 40 db below the level which would be produced by 100% modulation of the transmitter with a single frequency sine wave where 100% modulation is defined as the synchronizing pulse peak level.

The test equipment is set up as shown in Figure 5-29. No modulation is applied to the video input so that the only modulation in the output is that induced by hum and noise generated in the equipment. The low pass filter removes noise and hum above 15 KHz. The hum and noise in the output is detected on an oscilloscope.

5.8.4 Harmonic and Spurious Outputs

The purpose of this test is to measure all harmonic, subharmonic and spurious radiation from the transmitter as an indication of filtering required in future transmitters of similar design to insure that these radiations are at least 60 dB down from the peak visual carrier. A probe is inserted into the output waveguide to sample the RF output as is shown in the equipment block diagram of Figure 5-30. The sampled RF signal then enters the band reject filter prior to the spectrum analyzer. The band reject filter suppresses the carrier and permits the measurement of the low level harmonics and spurious signals.

Testing will be performed by driving the exciter at normal black level, with color subcarrier sync signals. The band reject filter is detuned and the variable attenuator adjusted so as to achieve a suitable reference level for the carrier peak visual power. The band reject filter is then adjusted to suppress the carrier and prevent overdriving the spectrum analyzer. The attenuation between the probe and the analyzer is reduced in calibrated amounts and the relative levels of subharmonics, harmonics, and spurious signals measured. Levels from 600 MHz to 10 GHz are recorded except the visual passband of the transmitter is omitted.

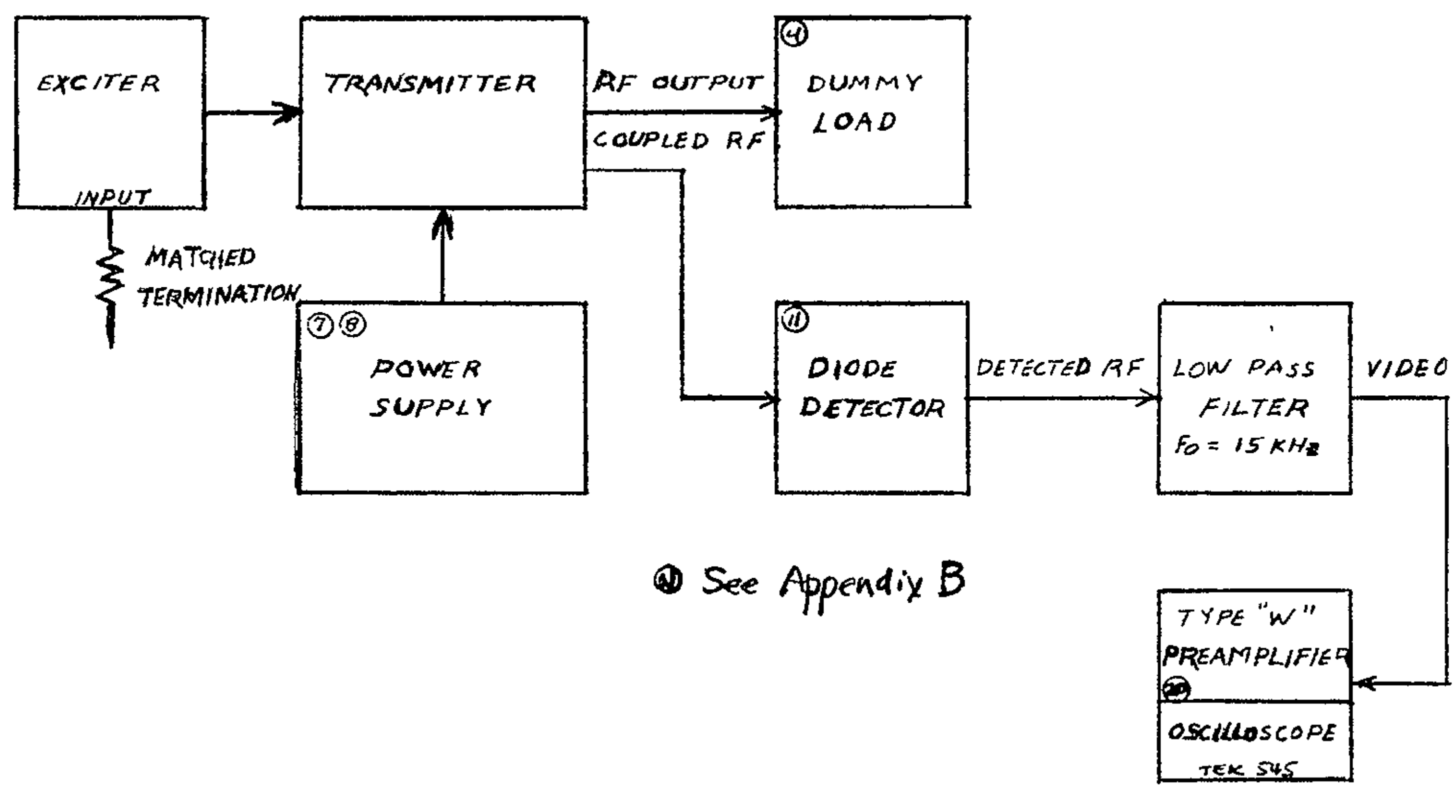


FIGURE 5-29. TEST EQUIPMENT SETUP FOR HUM AND NOISE MEASUREMENTS

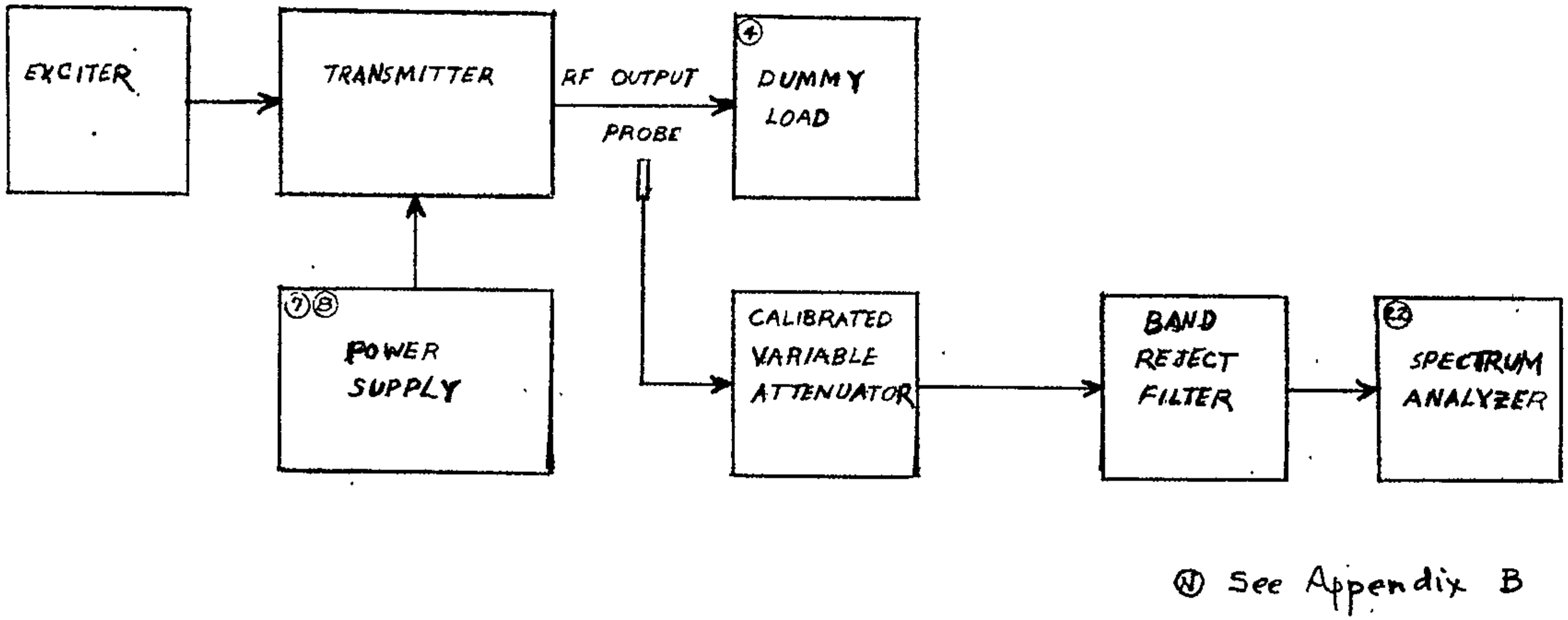


FIGURE 5-30. TEST EQUIPMENT SETUP FOR HARMONIC AND SPURIOUS OUTPUTS MEASUREMENTS

Since the measurements are made in half height waveguide (WR 975), precautions must be observed. This waveguide will not support frequencies below 605 MHz so no measurements will be required below this frequency. This waveguide will support spurious modes above 1210 MHz; therefore, measurements with the probe must be considered as indicative rather as absolute measurements of harmonic levels. By judiciously probing the waveguide in different physical positions, the likelihood of "missing" a harmonic signal by probing into a null region will be greatly reduced. Elaborate schemes for measuring harmonic levels in waveguide use this basic multiple sample approach plus an analysis routine but this is considered outside the scope of the present study Instead, a simple level estimate based on harmonic voltage spatial pattern, will suffice for this order of magnitude measurement.

Care must also be observed in using the probe. Spurious results can be obtained with certain probe configurations. Therefore, probes should be calibrated in a section of TEM line over the frequency range of interest to verify that valid data is obtained.

5.8.5 Controlled Carrier Operation

These tests are to evaluate the controlled carrier mode of the AM-TV transmitter operation. The measurements in these tests will be compared with those for the transmitter in the normal mode of operation, and judgements made as to the effectiveness of the controlled carrier mode.

The tests described in Section 5.8.2 are repeated for transmitter operation in the controlled carrier mode. Specifications for each test remain as for the previous tests. Specific items of interest are possible improvements in transmitter system efficiency and effects on TV picture quality when carrier control is used.

5.8.6 Power Supply Regulation and Effects of Transient Loading

This test is to evaluate the performance of the power conditioner unit and LC energy storage filter when subjected to normal transient conditions. These transient conditions would be caused by radical changes in the picture content of the visual carrier. This test will be performed with the transmitter operating in the controlled carrier mode and the non-controlled carrier mode to enable the evaluation of additional possible improvements.

The transmitter and test equipment will be set up as shown in Figure 5-31. A pulse generator drives the exciter and provides a transition in the APL during a frame interval. Thus, the picture level changes abruptly from one level to another. This provides the transient load on the power supply, power conditioner, and LC filter. The oscilloscope is synchronized to the pulse generator and displays the voltage waveforms at the required points in the system. Thus, any effects of the transient will be observed in the oscilloscope waveforms.

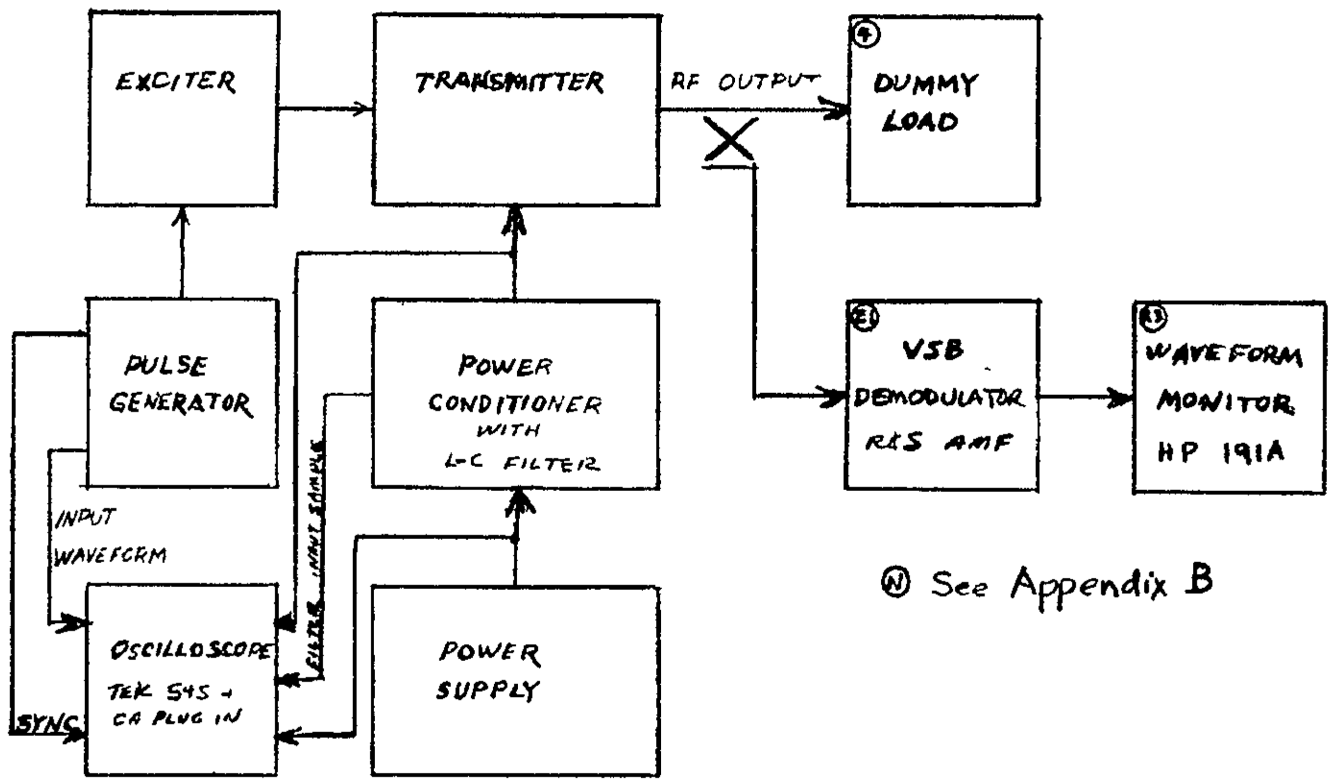


FIGURE 5-31. TEST EQUIPMENT SETUP FOR EFFECTS OF TRANSIENT LOADING ON THE POWER SUPPLY

5.8.7 Upper and Lower Sideband Attenuation in the Visual RF Channel with VSB and Color Image Filters

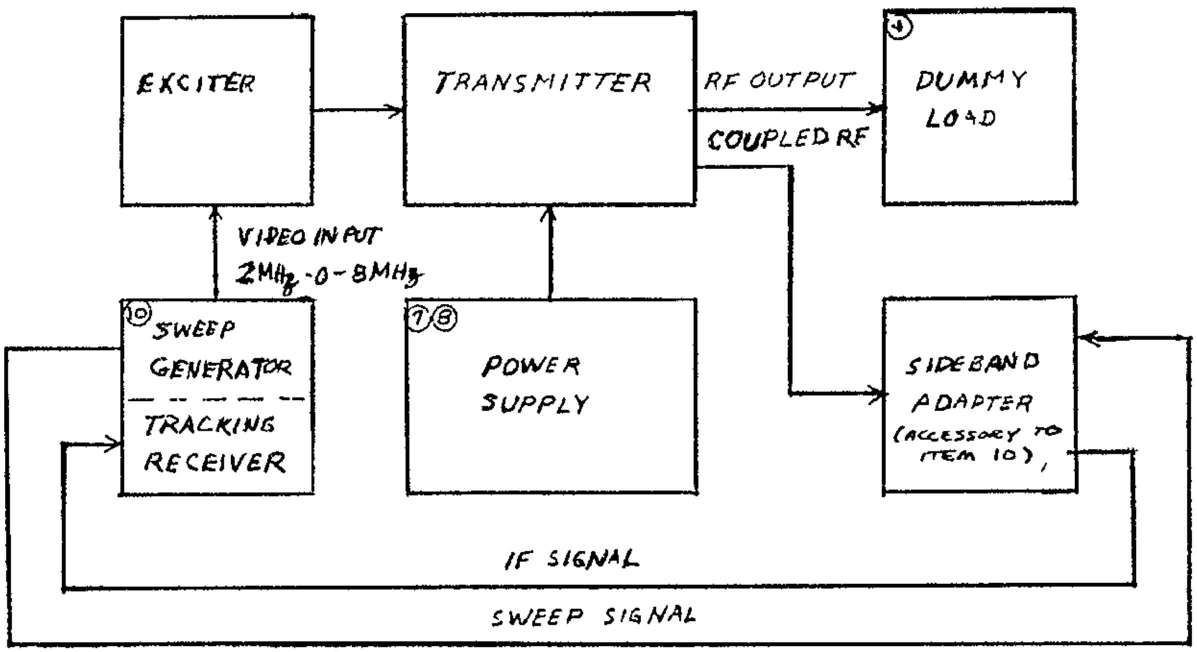
This test is to measure the upper and lower sideband attenuation and verify that the transmitter meets bandpass specifications. The lower sidebands are required to be not greater than -20 dB from the reference at 200 KHz. The color subcarrier image is required to be not greater than -42 dB from the reference. The lower sideband is defined as -4.25 to -1.25 MHz from video carrier and the upper sideband is defined to be from +4.75 MHz to +7.75 MHz from the video carrier.

The test to be performed is similar to that described in Section 5.8.3. That test measured the video passband response whereas this test measures the RF response in both the passband and the sidebands. The equipment set up is shown in Figure 5-32.

The sweep generator drives the exciter with a sawtooth from 0 to 8 MHz, with a test amplitude of 0.45 of the voltage of the synchronizing pulse peaks. The output of the transmitter is doubly converted down in the sideband adapter and fed into the tracking receiver. Although the transmitter carrier has asymmetrical sidebands, the tracking receiver measures only a 1 KHz slot at an instant of time and thus gives true sideband response of the equipment.

5.8.8 Aural Channel Amplifier

The purpose of this test is to measure the input power requirements, output power, efficiency, heat dissipation, and mode of heat dissipation for the transmitter. The equipment set-up for the test is included in Figure 5-22. The transmitter is temporarily modified by inserting a directional coupler between the driver and the final amplifier for the purpose of measuring transmitter stage gains. During the test all input voltages, currents, power levels, coolant temperatures, and coolant flow rates are recorded. The input power requirements, output power, stage gains, efficiency, and means of heat dissipation are established for each portion of the transmitter under operating conditions.



N See Appendix B

FIGURE 5-32. TEST EQUIPMENT FOR SIDEBAND ATTENUATION MEASUREMENTS

The equipment is set up as shown in Figure 5-22 and the transmitter tuned for full output. The currents, voltages, powers, coolant temperatures and coolant flow rates are recorded. From these data, the transmitter efficiencies and heat dissipation factors are computed.

In addition, a test will be performed to measure the bandwidth characteristics of the aural transmitter. This test will measure the passband flatness and indicate possible degradation of the audio signal amplified in the transmitter.

The equipment for the test is set up as shown in Figure 5-33. A sweep oscillator scans the passband of the transmitter, and a portion of the transmitter rf is coupled off and the transmitter passband is measured on the network analyzer. The passband is recorded photographically.

A third aural channel test will measure the hum and noise modulation in the amplitude of the output of the transmitter that is contributed by the transmitter. The transmitter noise should be at least 50 dB below 100% amplitude modulation within the band of 50 to 15,000 Hz.

For these hum and noise tests, the AM noise and hum of the exciter will be measured first, and then the AM noise and hum of the entire transmitter measured. A comparison of the results will indicate the contribution of the transmitter alone.

The equipment is connected first as shown in Figure 5-34 to determine oscillator noise. No modulation is used so that the measured AM noise and hum are those of the exciter. Now, connecting the equipment as shown in Figure 5-29, the noise and hum of the entire transmitter is measured. The data of the two tests will permit a determination of the hum and noise induced by the transmitter.

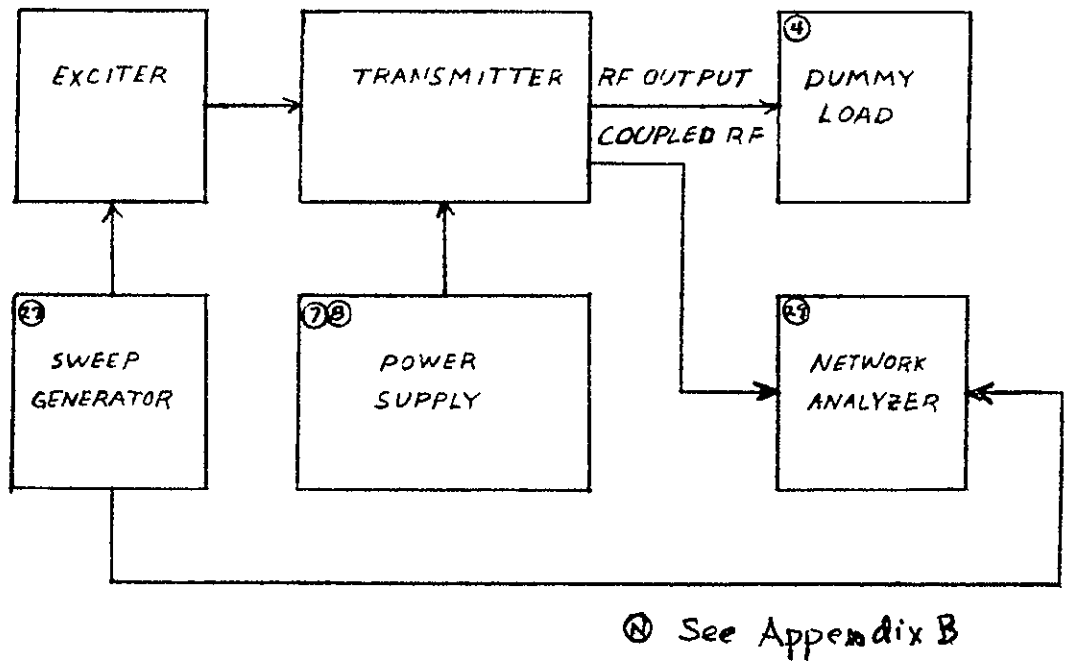


FIGURE 5-33. TEST EQUIPMENT FOR AURAL CHANNEL BANDWIDTH MEASUREMENT

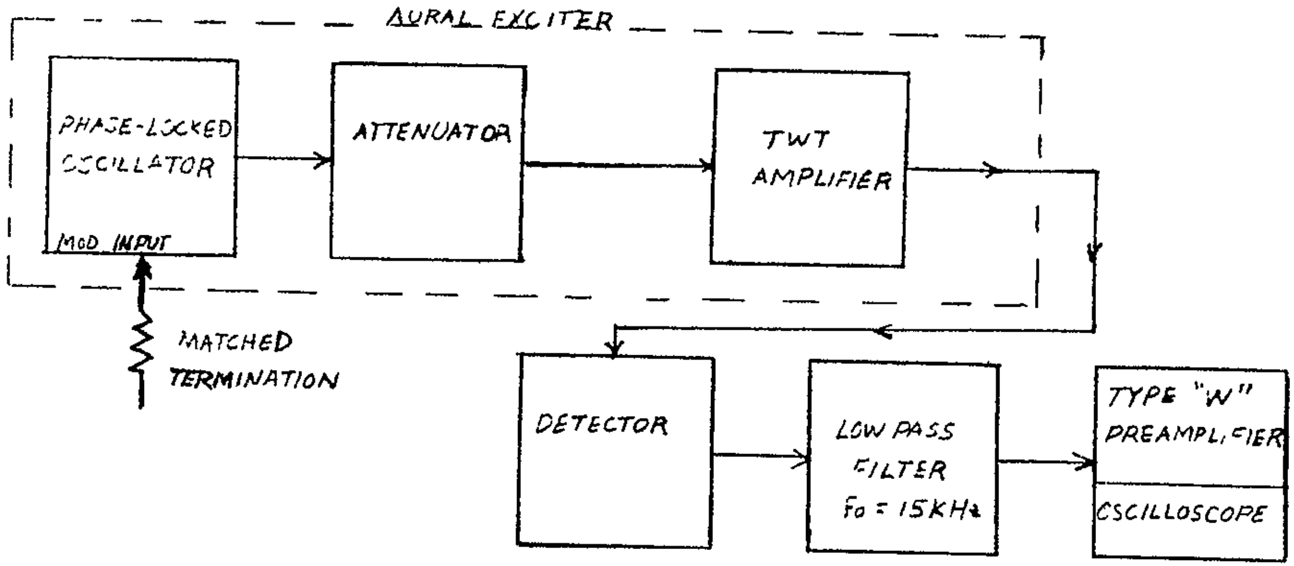


FIGURE 5-34. TEST EQUIPMENT FOR THE AURAL CHANNEL HUM AND NOISE MEASUREMENT

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APPENDIX A

PREVENTION OF MULTIPACTOR BREAKDOWN BY USE OF LOW IMPEDANCE COAXIAL LINE[6]

In order to reduce the probability of multipactor occurrence, it appears worthwhile to consider the use of low characteristic impedance lines. The following analysis applies to coaxial line; however, a similar approach would be valid for other forms such as ridged waveguide with small ridge gap spacing. A differential radius of about one millimeter at 800 MHz is considered a limiting value for the gap. Ostensibly, coaxial lines can be used in resonant filters.

If the outer conductor diamter is 1.625" and the gap is 1 mm, then the inner diameter is 1.545". The characteristic impedance is

$$\begin{aligned} Z_c &= 60 \ln (D_o/D_i) \\ &= 60 \ln (1.052) \\ &= 3.04 \text{ ohms.} \end{aligned}$$

Breakdown in air occurs with a field strength of about 30,000 V/cm so that a 1 mm gap can handle about 1.5 kV with a safety factor of two. Thus, the power handling capability of this line is

$$P = V^2/Z_c \cong 370 \text{ kW.}$$

In high power klystrons, a maximum safe RF potential gradient in vacuum with copper electrodes is about 900 kV/inch; for conservative operation a gradient of 600 kV/inch is desired. With surfaces other than copper, such as molybdenum or tungsten, the permissible gradients are higher since the materials are less apt to produce surface cracks under operation. Assuming a peak value of 600 kV/inch, a safe vacuum breakdown average power level in a 1 mm gap, 3.04 ohm, copper coaxial line is

$$\begin{aligned} P &= \left[\frac{600 \times 10^3}{25.4 \text{ mm/in.}}\right]^2 \times 1/4 \times 1/(3.04) \\ &= 47 \text{ megawatts,} \end{aligned}$$

which includes a 2:1 safety factor. The attenuation of a matched 3.04 ohm coaxial line can be computed from the following:

$$\alpha = \frac{179.5}{Z_c} \times 10^{-9} \sqrt{f} \quad (1/a + 1/b)$$

where

f = 800 MHz

a = inner conductor radius = 0.772"

b = outer conductor radius = 0.812"

Thus, the matched attenuation at 800 MHz is

$\alpha = 4.23 \times 10^{-3}$ dB/inch

= 0.0625 dB/wavelength

= 1.5% loss/wavelength

APPENDIX B

Required Equipment for Multikilowatt Transmitter Tests

Item	Quantity	Description	Mfgr.	Model #
1	2	Coolant Flow Meter		
2	4	Coolant Temperature Meters		
3	1	TV Signal Generator	Rhode & Schwarz	SDFA
4	2	5 KW Dummy Load, 50 OHM	Bird	872
5	1	Directional Coupler, 20 dB 100 W		
6	2	Power Meter	H.P.	431
7	1	Power Supply 1.5 KV 1.0A	Sorenson	DCR 1500-1
8	1	Power Supply 5 KV @ 3.0 A	G.E.	
9	2	Attenuator 20 dB, 1 W		
10	1	Sideband Response Analyzer	Rhode & Schwarz	SWOF
11	1	Monitoring Diode		
12	1	Processing Amplifier	Grass Valley	900T, 940
13	1	Gain and Phase Adjust	Grass Valley	941
14	1	Burst Amplifier	Grass Valley	966
15	1	TV Test Signal Generator	Tektronics	140
16	1	Aural FM Generator	Fairchild	MO(L)-100 XB
17	2	TWT Amplifiers	GE	

Appendix B (cont.)

Item	Quantity	Description	Mfgr.	Model #
18	1	Vectorscope	Tektronics	520
19	1	Group-Delay Measuring Equipment	Rhode & Schwarz	LFM
20	1	Oscilloscope Preamplifier	Tektronics	"W"
21	1	Vestigal Demodulator	Rhode & Schwarz	AMF
22	1	Spectrum Analyzer	Hewlett Packard	8551
23	1	TV Waveform Monitor	HP	191A
24	1	TV Sync Generator	RCA	TG-3
25	1	TV Color Bar Generator	RCA	TG-4
26	1	Color Broadcast Monitor	RCA	
27	1	Sweep Generator	HP	
28	1	Counter	HP	5246/5254
29	1	Network Analyzer	HP	8410
30	1	True RMS Voltmeter	Ballantine	323
31	1	Peak Reading, Tunable Voltmeter	Empire	NF-105
32	1	TV Monitor Receiver		
33	2	Directional Coupler, 20 dB, 500 W		
34	1	Directional Coupler 30 dB, 5 KW		
35	1	Side Band Adaptor	Rhode & Schwarz	

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